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FAR-FIELD UNDERWATER-BLAST INJURIES
PRODUCED BY SMALL CHARGES

Donald R. Richmond, et al

Lovelace Foundation for Medical Education
and Research

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1 July 1973

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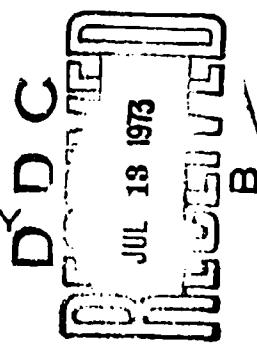
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PREPARING AGENCY
Lovelace Foundation
for
Medical Education and Research
Albuquerque, New Mexico

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Based on the results of this study, a safe impulse level of 2 to 3 psi·msec for unprotected swimmers, head above the surface, was proposed. This safe impulse level was discussed in relation to the underwater blast-wave parameters in the test pond and existing response data for personnel.			

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ABSTRACT

Underwater-blast injuries, at increasing ranges beyond the lethal zone from small charges, were studied using animals. The study was conducted in an artificial pond that measured 220 by 150 ft at its surface. The pond was 30 ft deep over its 30- by 100-ft center portion. Sheep, dogs, and a few monkeys were exposed to the blast oriented vertically in the water (long axis perpendicular to the surface). Most were exposed to the blast at 1-ft depths, heads above the surface, and a limited number at 2- and 10-ft depths. Explosive charges were mostly bare spheres of Pentolite weighing 0.5, 1, 3, and 8 lb. All charges were detonated at 10-ft depths. The immersion-blast injuries were of minor severity and consisted mainly of lung hemorrhages and small areas of contusions in the gastrointestinal tract. The incidence and severity of the injuries were correlated with the impulse in the underwater-blast wave. Tests were run with dogs beneath the surface to evaluate eardrum rupture. The subjects were right-side-on to the blast, and a probit analysis run on the data for the right ears yielded an impulse of 22.6 psi·msec for 50-percent eardrum rupture.

Based on the results of this study, a safe impulse level of 2 to 3 psi·msec for unprotected swimmers, head above the surface, was proposed. This safe impulse level was discussed in relation to the underwater-blast-wave parameters in the test pond and existing response data for personnel.

FOREWORD

This report presents the results of tests run to determine the far-field underwater-blast injuries in large animals (mostly sheep). The tests were carried out in Lake Christian an artificial pond on Kirtland Air Force Base (East), Albuquerque, New Mexico.

The work was performed by the Lovelace Foundation for Medical Education and Research under contract with the Defense Nuclear Agency, Contract No. DASA-01-71-C-0013. The funds were provided by the U.S. Navy Bureau of Medicine and Surgery (BUMED 7111) and the work was under the direction of the U.S. Naval Ordnance Laboratory (NOL). The NOL representative was Miss Ermine A. Christian of the Explosions Research Department. Because of limited annual funding, the study spanned a 3-year period.

Twenty-one tests were run from September through November in 1970 involving 42 sheep, six monkeys, and six dogs exposed at 1-ft depths.

Fifteen tests were run from May through July in 1971 with 38 sheep and seven dogs exposed mostly at 2- and 10-ft depths. A preliminary data report was prepared in December 1971.

Nineteen tests were run in July and September of 1972 involving 21 sheep and 24 dogs exposed at depths of 1 ft or less.

The information gained in this study can be applied to estimating safe and deterrent ranges for swimmers in the environment of underwater explosions.

ACKNOWLEDGMENTS

The valuable assistance of the following Lovelace Foundation personnel in carrying out this study is gratefully acknowledged: Mr. Allie Shaw for animal handling and assisting in the postmortem examinations; Mr. William Jackson and Mr. Albert Trujillo for fabricating many items at the test pond; Mr. Jess Hunley for placing and firing the charges; Mr. Takeshi Minagawa for photographing organ specimens and illustrative materials; and Mrs. Berlinda S. Martinez for production of the report including preparing numerous figures and tables, editing, and typing the report.

The experimental work discussed in this manuscript was conducted according to the principles enunciated in the "Guide for Laboratory Animal Facilities and Care," prepared by the National Academy of Sciences-National Research Council.

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INTRODUCTION

What is a safe distance from an underwater explosion for personnel in the water? The problem this question poses has existed for a long time. In particular, what is the closest range for no-effects from a given underwater explosion for unprotected swimmers? Although there is some information on the response of personnel clothed in diving gear, summarized in reference 1, data for unprotected swimmers are notably meager. Usually, volunteer swimmers were at such great distances from underwater explosions that the findings were not useful (references 1 through 3). The only safety criterion existing today for unprotected personnel in the water is...get out of the water during the explosion. The Naval Ordnance Laboratory (NOL)-Lovelace Test Facility provided an ideal opportunity to conduct systematic tests to determine the far-field underwater-blast effects in biological specimens. The tests could be run under carefully controlled conditions wherein the blast-wave parameters were measured precisely with the most up-to-date piezoelectric gages.

The purposes of this study were: (1) to determine how the biological effects of underwater blast fell off with range beyond the lethal zone from small charges, (2) to obtain some information on the response of ears to underwater explosions, and (3) to correlate the effects with the impulse of the underwater-blast wave so that the results could be scaled to other exposure conditions.

METHODS

The Test Pond

The test pond was 220 by 150 ft and was 30 ft deep over its 30- by 100-ft center portion, figures 1 and 2. The entire pond was lined with black polyvinyl plastic 20 mils thick. A 6-inch-deep layer of sand was located beneath the plastic in the 30-ft-deep portion of the bottom. The sides of the pond had a 2-to-1 slope. Two sets of rigging spanned the pond in a north-south direction. The main rigging, located 80 ft from the west end, consisted of a grid 14 by 24 ft which could be raised and lowered by an electric winch on the south bank. The other rigging was approximately 30 ft from the east end of the pond. Its center grid was 5 by 10 ft which could be raised and lowered by a hand winch on the south bank. The test pond contained approximately 3.2 million gallons of tap water.

The ambient air pressure at the pond was 12.0 psia.

General Procedures

In general, three animals were exposed per test. With few exceptions, they were all at the same range on a given shot. All the test subjects were mounted vertically in the water (long axis perpendicular to the surface). The depth of the sheep was measured from the water surface to their xiphisternum. Dogs and monkeys were submerged to about their glottis level, shoulders beneath the surface, but were designated at 1-ft depths. All animals were right-side-on to the charge.

Animals Vertical in the Water

The first tests were run by placing animals at increasing distances from the charges. The animals were at 1-ft depths, and the 1-, 3-, or 8-lb charges were detonated at 10-ft depths. Based on the initial results from the 1-lb charge firings, tentative biological endpoints (a given severity of injury) and corresponding impulse levels were chosen. These were to be evaluated with dogs and monkeys on the surface and with subjects beneath the surface. The endpoints were: threshold for lung injury (about $40 \text{ psi} \cdot \text{msec}$), threshold for G.I. tract contusions (near $20 \text{ psi} \cdot \text{msec}$), and no-effect level (approximately $10 \text{ psi} \cdot \text{msec}$ or less).

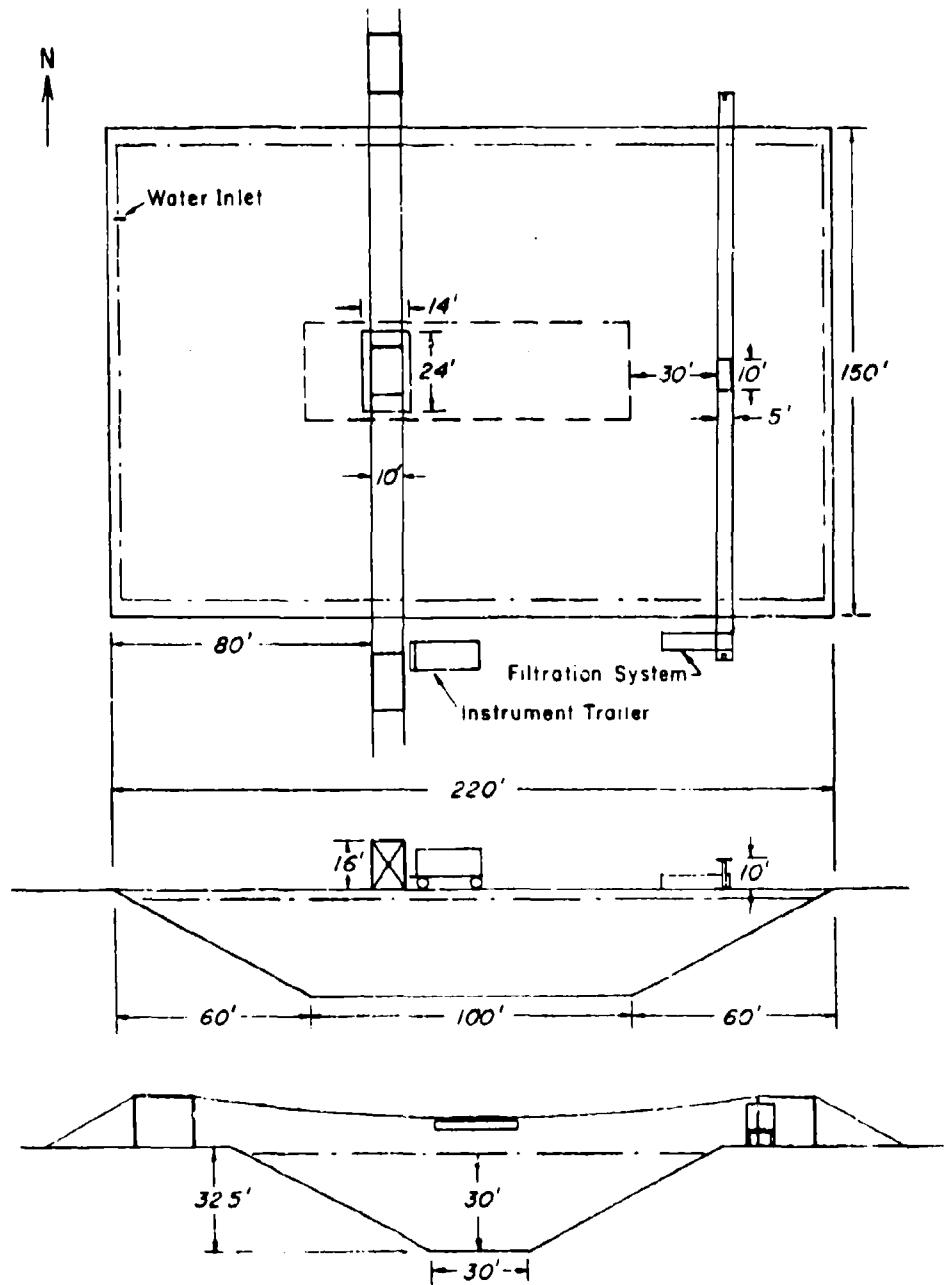


Figure 1.--Diagram of test pond facility.



Figure 2. - Test pond viewed from the southwest corner.

The 30-ft-deep portion of the pond was too small to confirm a no-effect range with 3- and 8-lb charges with animals at 1-ft depths. It was soon learned that even for the 1-lb charge it was necessary to work at ranges beyond 100 ft in order to obtain a certain no-effect range. A rigging was placed across the east end of the pond so that animals could be exposed at the 130-ft range. The charge was 60 ft from the west end of the pond, and the targets were in water 15-ft deep.

Later in the testing, animals were placed at 2- and 10-ft depths to confirm some of the endpoints in targets beneath the surface. It was necessary to use 0.5-lb charges to get impulses of 10 psi msec or less for subjects at 10-ft depths.

The life-support system that supplied air to the sheep at 2- and 10-ft depths consisted of a face mask (made from polyethylene bottles) having an air inlet hose in the side and a one-way outlet valve in the front of the mask. It covered the animal's nose and mouth and was held in place by four strings tied to the back of the head. The compressed air was delivered to the mask via plastic tubing connected to a manifold of five pressure regulators fastened to two air bottles in series. When animals were exposed at 10-ft depths, 2 psi was applied to the system once the mask was attached to the animal. The pressure then was increased to 6 psi and the rigging lowered to place the animals at the 10-ft depth. Following the detonation, the animals were returned to the surface within 1 min, the delivery pressure reduced to 2 psi, and the face masks quickly removed and inspected for water.

A summary of the shots fired, the ranges used, and the animal numbers are given in tables 1 through 4 for each charge weight. In addition to those listed in the tables, four shots were taken to get additional bottom reflection data.
Animals Horizontal to the Surface

A series of four tests was run with the animals horizontal to the surface, table 5. On two of the tests, five animals were at 0.5 ft depths in the prone and supine positions, and one was in the upright orientation at a 1-ft depth. On the two tests with animals at 1-ft depths, they were all prone. The depths were measured from the water surface to the under surface of their trunks.

Eardrum Response Tests

Eight tests were run specifically for eardrum response data, table 6. Dogs were used because the size and geometry of the eardrum and middle ear

Table 1.--Ranges at which 0.5-lb charges were fired to subject targets vertical in the water to anticipated impulse levels of 10 psi·msec and less.

Shot No.	Slant Range, ft	Target Depth, ft	Animal Numbers
181	110	1	Sheep Nos. 136, 129, 143
182	110	1	Sheep Nos. 138, 144, 130
178	93	2	Sheep Nos. 247, 120, 124
166	100	10	Sheep Nos. 237, 55, 49
169	100	10	Sheep Nos. 108, 121, 114
170	100	10	Sheep Nos. 123, 101, 122
180	100	10	Dogs Nos. 121, 122, 118

Table 2. --Ranges at which 1-lb charges were fired to subject targets vertical in the water to anticipated impulse levels of from 40 to 2 psi·msec.

Shot No.	Slant Range, ft	Target Depth, ft	Animal Numbers
136	26	1	Sheep Nos. 156, 185, 189
152	26	1	Monkey No. 76; Dog No. 224
137	30	1	Sheep Nos. 118, 167, 169
151	34	1	Monkey No. 80; Dog No. 208
138	34	1	Sheep Nos. 115, 116, 171
139	38	1	Sheep Nos. 158, 177, NN
141	46	1	Sheep Nos. 188, 165, 191
151	46	1	Monkey No. 43; Dog No. 207
179	56	1	Dogs Nos. 213, 212, 161
153	56	1	Monkey No. 84; Dog No. 221
145	56	1	Sheep Nos. 211, 217, 212
203	56	1	Dogs Nos. 116, 200, 210
205 ^a	56	1	Dogs Nos. 220, 110, 208
147	78	1	Sheep Nos. 162, 199, 228
154	78	1	Monkey No. 85; Dog No. 216
207 ^a	78	1	Dogs Nos. 261, 102, 262
209 ^a	78	1	Dogs Nos. 117, 233, 163
155	110	1	Monkey No. 33; Dog No. 00
156	110	1	Sheep Nos. 222, 172, 193
158	110	1	No animals. To get P-T at 110 ft for shots 155 and 156.
190	130	1	Sheep Nos. 66, 64, 65
191	130	1	Sheep Nos. 67, 68, 69
192	130	1	Sheep Nos. 71, 70, 72
193	130	1	Sheep Nos. 73, 74, 75
175	33	2	Sheep Nos. 102, 116, 104
176	54	2	Sheep Nos. 106, 107, 111
177	83	2	Sheep Nos. 118, 50, 119
168	48	10	Sheep Nos. 103, 115, 105
163	48	10	No animals.
167	84	10	Sheep Nos. 113, 148, 117
164	84	10	No animals.
171	84	10	Sheep Nos. 110, 125, 109

^aCharge was TNT.

Table 3.--Ranges at which 3-lb charges^a were fired to subject targets vertical in the water to anticipated impulse levels of 40, 20, 10, and 6 psi·msec.

Shot No.	Slant Range, ft	Target Depth, ft	Animal Numbers
143	36	1	Sheep Nos. 179, 97, 173
144	61	1	Sheep Nos. 215, 225, 201
146	72	1	Sheep Nos. 229, 224, 214
148	97	1	Sheep Nos. 206, 184, 205
149	97	1	No animals. To get P-T for shot 148.

^aCharge actually weighed 2.6-lb.

Table 4.--Ranges at which 8-lb charges were fired to subject targets vertical in the water to anticipated impulse levels of 40 and 20 psi·msec.

Shot No.	Slant Range, ft	Target Depth, ft	Animal Numbers
140	52	1	Sheep Nos. 186, 194, 161
142	60	1	Sheep Nos. 114, 187, 85

Table 5.--Ranges at which 1-lb charges were fired with targets horizontal to the surface.

Shot No.	Slant Range, ft	Target Depth, ft	Animal Numbers
187	13	0.5	Sheep Nos. 55 ^a , 56, 57
188	13	0.5	Sheep Nos. 58, 59, 60
189	16	1.0	Sheep Nos. 62, 61, 63
183	26	1.0	Sheep Nos. 141, 134; Dog No. 231

^aAnimal was oriented vertically in the water right-side-on to charge.

Table 6.--Ranges at which 1-lb charges^a were fired with dog ears at 1-ft depths.

Shot No.	Slant Range, ft	Animal Numbers
194	20	Dogs Nos. 204, 217, 215
195	40	Dogs Nos. 1, 217', 218
204	40	Dogs Nos. 200, 116, 210
208	40	Dogs Nos. 261, 102, 262
210	40	Dogs Nos. 263, 117, 163'
200	45	Dogs Nos. 120, 253, 200'
206	45	Dogs Nos. 220, 100, 208
197	60	Dogs Nos. 205, 163, 202

^aAll charges were TNT.

approximate man's more so than other animals. The 24 dogs were oriented vertically in the water with their ears exactly at 1-ft depth. They were right-side-on to the charge with their right ear facing the charge. In order to maintain the exact position of the head, freshly sacrificed animals were used. After sacrifice, the pinna of the ear was clipped to approximate the size of the humans. Twelve of the 24 dogs used in this series had been exposed previously at 1-ft depths, head above the surface, in the first series of tests mentioned. To evaluate the extent of ear injury, the middle ear was dissected open from the brain side of the skull and then photographed.

Animals

One hundred and one Columbia-Rambouillet female sheep, 37 Dalmation dogs, and six rhesus monkeys were utilized on these tests. In addition, nine sheep and one dog were used as control animals to check out the effects, if any, that were due to handling of the animals, tethering them beneath the grid, and subjecting them to going beneath the surface using the life-support system. All the test subjects were autopsied 2 hours following the test. At postmortem, the entire length of the G.I. tract was examined carefully. It was slit open, its contents washed out, and the condition of the mucosal lining in the contused areas was recorded.

Explosive Charges

The explosive charges used in these experiments were bare spheres of cast Pentolite and 1-lb blocks of pressed TNT. The Pentolite spheres had 5/16-inch-diameter detonator wells. The charges were fired with electric blasting caps, DuPont No. E-99. The charge weights were designated at 0.5 lb, 1 lb, 3 lb, and 8 lb. The actual measured weights of these charges, mean and range, were as follows: 0.5 lb, 0.487 (0.485 to 0.492) lb; 1 lb, 1.052 (1.047 to 1.058) lb; 3 lb, 2.618 (2.608 to 2.626) lb; and 8 lb, 8.373 (8.369 to 8.377) lb. All the charges were detonated at 10-ft burst depths.

Pressure-Time Measurements

There were four channels of pressure-time measuring instrumentation. The methods and equipment used for measuring and recording the underwater-blast wave basically are those described in references 4 and 5. The pressure-time gages were a recent modification of the NOL gage Type B. Sensing elements of

the gages consisted of four 1/4-inch-diameter tourmaline discs mounted in a Tygon⁽⁸⁾ tube filled with silicone oil (Dow-Corning No. 200 dielectric oil). Signals from the gages were passed through a cathode-follower K amplifier unit and recorded on a dual-beam oscilloscope (Tektronix Model 555 with Type D pre-amplifier plug-in units). To ensure accurate time measurements, timing marks were placed on the oscilloscope with a time-marker generator.

On each trial, recording gages were placed at the same ranges and depths as were the animals. The only exception to this routine was on Shots 187 and 188 where targets were at 0.5-ft depths and the gages were 1 ft deep. Attempts were made to locate the gages away from the animals so that the subjects themselves would not alter the pressure-time pattern. Trigger gages were located just upstream from the recording gages so that their signals would initiate the sweep of the oscilloscope.

The system was calibrated by the voltage-step method. A voltage-step generator supplied a known voltage impulse to the system. The calibration voltage step and time markings were placed on separate oscillograph records immediately before each test.

Pressure recordings were enlarged photographically and semilogarithmic plots made for each one. Pressure values were obtained from the curves by the following equation:

$$P = \frac{C_s E_c}{KA} \frac{\Delta P}{\Delta V}$$

P = pressure, psi

C_s = standard capacitance, microfarads

E_c = calibration voltage, volts

ΔP = deflection on record due to pressure

ΔV = deflection on record due to calibration

KA = gage sensitivity, coulombs $\times 10^{-12}$

The KA of the gages was determined at NOL.

A computer program was developed to extrapolate the pressure curve back to one-half the rise time on a particular record to obtain the peak pressure. This added area under the curve was included in the integration for the impulse.

The theta and energy parameters likewise were furnished by the computer. In determining the peak pressure in the bottom reflection records, the curves were not extrapolated back to one-half the rise time.

RESULTS

Animals Vertical in the Water

Nature and Severity of Underwater-Blast Injuries

In the main test series wherein animals were oriented vertically in the water, there were no deaths from blast injuries. As will be mentioned later, two of the subjects died as a result of an inadequate life-support system when they were located at the 10-ft depths. The only animals that from external signs appeared hurt were the three sheep from Shot 136 which were tested at a 1-ft depth and at a slant range of 26 ft from a 1-lb charge. They were docile and remained lying down after removal from their mounts but were on their feet at 5 minutes when the raft was docked. They did not run around the raft as the other sheep did when released from their mounts.

The immersion-blast injuries were, for the most part, confined to the lungs and G.I. tract. Some eardrums were ruptured in those animals tested beneath the surface at the shorter ranges. The injuries were similar to those repeatedly described in the literature (i.e., references 2, 6, and 7) but of minor severity. There were no instances of either ruptured lungs or ruptured G.I. tracts. At the shorter ranges, animals sustained slight amounts of lung hemorrhages as illustrated in figure 3 and multiple contusions of the G.I. tract, figures 4 and 5. The contusions were small in area and scattered throughout the small intestine, caecum, large intestine, including the spiralis, ansa terminalis, and rectum. There was only one case of contusions in the stomach. Some of these contusions, even though small in area (1/2 in or less), were of sufficient severity to ulcerate the mucosal layer of tissue that lines the lumen of these organs, figure 5. These ulcerations would account for small blood clots found in the feces of many of the animals. In no instance did the blood clots in the feces amount to more than a few drops of blood. This commonly would cause the animals to defecate soon after their removal from the water. In general, the number and size of these contused areas would decrease with distance from the charge. The most far-field lesions were a few petechia or small hyperemic



Figure 3.--Slight lung hemorrhage from Sheep No. 186, Shot No. 140.
[Target at a 1-ft depth, 52 ft from an 8-lb charge detonated
at a 10-ft depth. The peak pressure was 493 psi; the
impulse was 36.5 psi·msec.]

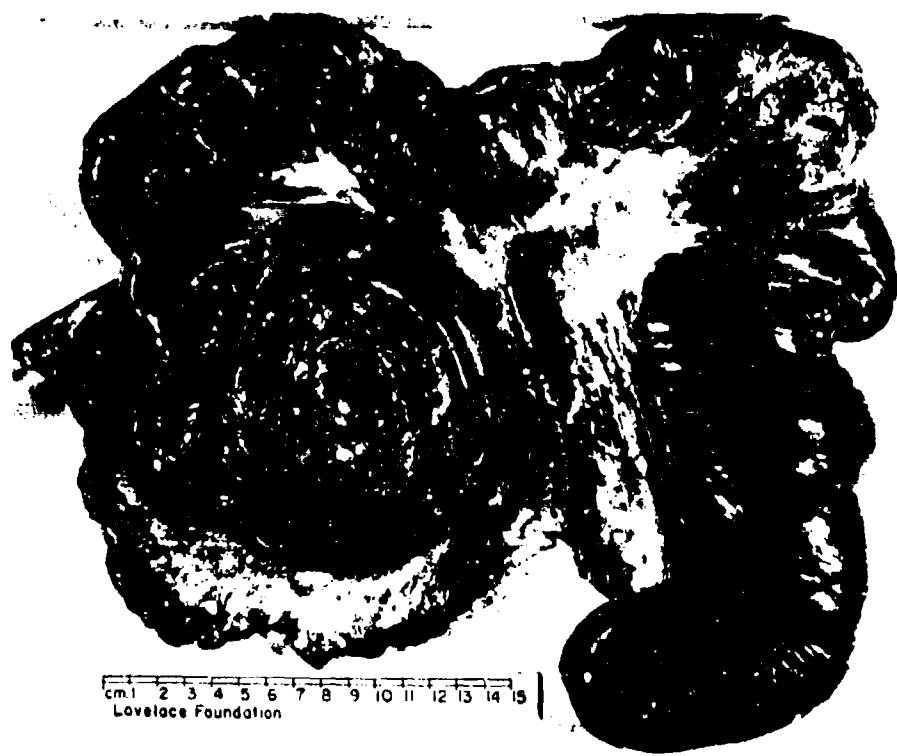


Figure 4.--Lower portion of G.I. tract from Sheep No. 186, Shot No. 140. [Multiple contusions of spiralis, ansa terminalis, and rectum (lower left). Target at a 1-ft depth, 52 ft from an 8-lb charge detonated at a 10-ft depth.]



1 cm 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Lovelace Foundation

Figure 5.--Lower portion of G.I. tract from Sheep No. 161, Shot No. 140. [Large colon opened to show ulceration of mucosal lining (upper hemostat). Target at 1-ft depth, 52 ft from an 8-lb charge detonated at a 10-ft depth. The peak pressure was 493 psi; the impulse was 36.5 psi·msec.]

spots on the lower portion of the rectum near the anus. A more severe form of scattered multiple petechia lining the rectum is illustrated in figure 6.

The blast effects recorded in animals from the eight charge-target configurations are listed in tables A-1 through A-10, appendix A. Included in each table are the peak pressures, impulses, and durations (cutoff times) measured at the animals' designated depths. Also included are pressure-time values calculated at 2- and 3-ft depths in connection with the animals at 1- and 2-ft depths, respectively. Unless stated otherwise, pressure-time values pertain to those measured at the animals' designated depths. The contusions of the G.I. tract were termed as contusions if ulcerations of the mucosal lining were associated with any of them and were termed as mild contusions if there were no ulcerations of the mucosal lining. Exceptions to this scheme were noted; i.e., the subject had only mild contusions, yet there was a drop or two of clotted blood observed in its feces.

Underwater Blast Injuries in Relation to Distance From 1 lb-Charges for Animals at 1-ft Depths

Lung Hemorrhage

The incidence of lung hemorrhage in animals tested at 1-ft depths, in relation to range from 1-lb charges, appears in figure 7a. At the 26-ft slant range, slight lung hemorrhages occurred in the dog and monkey, and petechial hemorrhages were found in the lungs of one of the three sheep, table A-4 of appendix A. There were no lung lesions detected in animals at ranges beyond 26 ft.

Gastrointestinal Lesions

The general pattern of G.I. tract damage in animals at 1-ft depths, in relation to slant ranges from 1-lb charges, is given in figure 7b and table A-4 of appendix A. The general stepdown pattern of severity of G.I. tract lesions with range can be seen in figure 7b. Contusions of the more severe form extended out to 35 to 40 ft. Beyond the 60-ft range, the lesion found was a 1-in diameter mild contusion in the caecum of a sheep at the 78-ft range. All 12 sheep tested at the 130-ft range were entirely negative.

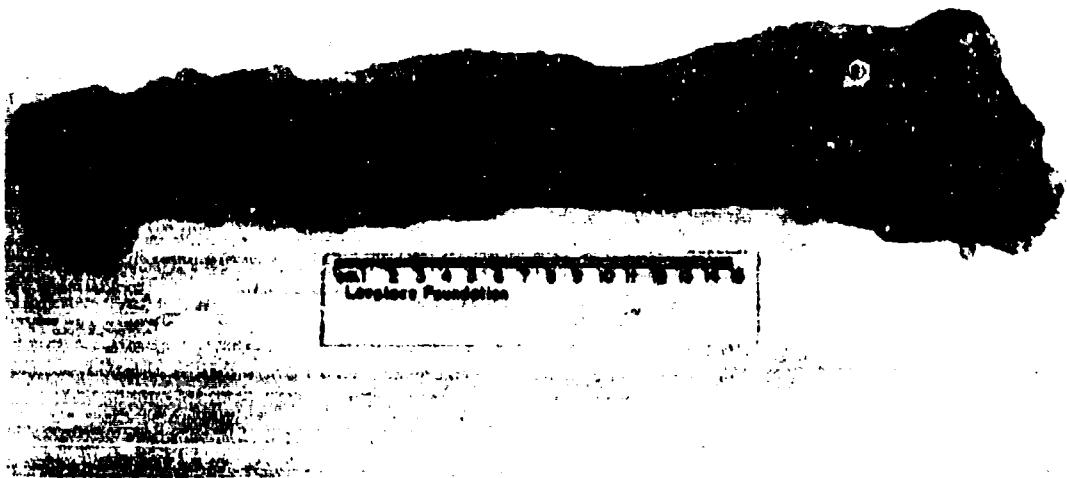


Figure 6.--The rectum of Sheep No. NN opened to show scattered petechiation and contusion, Shot No. 139. [The only other lesion was a 1/8-inch-diameter contusion in the caecum. Target at a 1-ft depth, 38 ft from a 1-lb charge detonated at a 10-ft depth. The peak pressure was 400 psi; the impulse was 25.8 psi·msec.]

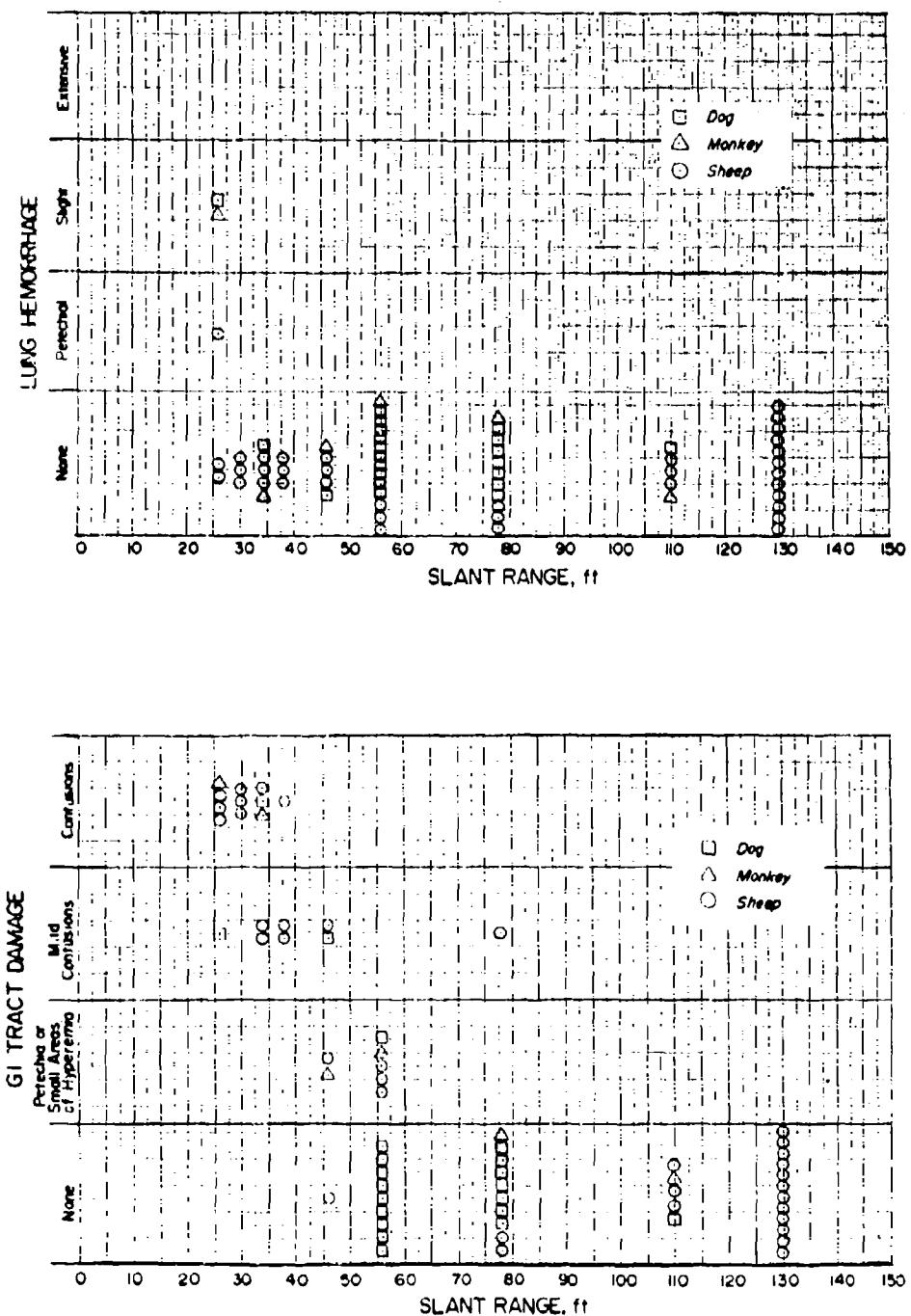


Figure 7.--The incidence of lung hemorrhage and G.I. tract injuries in animals at 1-ft depths in relation to slant range from 1-lb charges.

Underwater Blast Injuries as a Function of Impulse

The incidence of lung hemorrhages and G.I. tract lesions, along with the associated impulse values for all the animals exposed to the underwater blast in a vertical position, appear in figures 8a and 8b. The impulse values corresponding to each animal data point were those measured at the animals' designated depth, 1, 2, or 10 ft. As already mentioned, all these animals survived the underwater blast.

As seen in figure 8a, there was about a 50-percent incidence of slight lung hemorrhages at an impulse of 34 psi·msec. At an impulse on the order of 20 to 25 psi·msec, about half the animals sustained petechial hemorrhages. Below 20 psi·msec, there were no instances of slight lung hemorrhages. At impulses of 8 psi·msec and less, there was only one instance of petechial lung hemorrhage recorded in a sheep at 5.9 psi·msec. It is interesting to note that at the higher impulse levels some of the animals sustained no lung injury whatsoever. Lung lesions extended to lower impulse levels in those animals exposed to the underwater blast beneath the surface.

According to figure 7b, there was about a 50-percent incidence of G.I. tract contusions at impulse levels of 25 to 27 psi·msec. There were no contusions with ulcerations of the mucosal lining below an impulse level of about 15 psi·msec. About one-half of the animals subjected to an impulse of 21 to 23 psi·msec had either contusions or mild contusions in their G.I. tracts. The only lesions encountered below 10 psi·msec were two cases of animals with mild contusions at 6 to 7 psi·msec.

Animals Horizontal to Surface

Table A-9 of appendix A compares the severity of lung injury to that for the G.I. tract in six animals placed horizontal to the surface at 1-ft depths. The rationale was to expose the thorax and the abdomen of the animal at nearly the same depth and to the same impulse. Any air- or gas-containing organ, then, might be damaged to the same extent. The animals at the 26-ft range sustained slight lung hemorrhages and a few mild contusions of the G.I. tract. Those at the 16-ft range sustained slight to extensive lung hemorrhages and mild to multiple contusions with ulcerations into the lumen of the G.I. tract. As far as



Figure 8. --The incidence of lung hemorrhage and G.I. tract injuries as a function of impulse, psi·msec.

one can go in comparing the severity of damage between two different organ systems, the results indicate the extent of damage to be about the same. Possibly the lungs were more damaged than the G.I. tract.

Table A-10 gives the results obtained with horizontal subjects at 0.5-ft depths in the prone and supine positions along with one animal that was vertical in the water at the usual 1-ft depth. The vertical animal received extensive lung hemorrhage and multiple ruptures of the small intestine. None of the animals at 0.5-ft depths received G.I. tract ruptures, and the extent of lung hemorrhage was less than that found in the upright animal. There was not a remarkable difference in the extent of injuries in the supine compared to the prone animals. The lung weights of the supine sheep (1.45 and 1.49 percent) were slightly higher than those from the prone ones (1.23 and 1.27 percent).

Ear Injury in Dogs

Table 7 gives the eardrum rupture data for dogs in terms of the percent of area destroyed and the corresponding range and pressure-time parameters. Photographs illustrating the different severities of ear injury are shown in figure 9. In general, the eardrums on the right side of the head (the heads were right-side-on) were more damaged than the left ones. The right ears from animals at the 20-ft range were more damaged than those at the 40-ft range in terms of the area of the tympanum destroyed and ossicular damage. In three cases, eardrum rupture was bilateral; the rest were unilateral.

Figure 10 gives the results of probit analysis that was run relating right eardrum rupture as a function of the log impulse. The data for animals at the 40-ft range were divided into two groups. The results predict that 50 percent of the right ears would be ruptured at an impulse of 22.6 psi·msec. The 85-percent confidence limits were 21.7 to 25.2 psi·msec. For both right and left ears there was a 36-percent incidence of eardrum rupture in dogs at the 40-ft range. The mean impulse measured on these four shots was 22.0 psi·msec; the mean peak pressure was 320 psi.

Control Animals

Table A-11 of appendix A lists the lesions recorded in control animals that were used. During the period of these tests, the life-support system appeared inadequate. Some of the control animals died when lowered to a 10-ft depth.

Table 7.--Ear injury in dogs exposed right-side-on with their ears at 1-ft depths to underwater blasts from 1-lb TNT charges detonated at 10-ft depths.

Shot No.	Slant Range, ft	Peak Pressure, psi (Impulse, psi-msec) [Cut-Off Time, msec]	Dog No.	Eardrum Rupture, Percent Destroyed					
				Right		Left		Totals	
				Ruptured	Intact	Ruptured	Intact		
194	20	676 ^a (68.2) [0.214]	204 217 215	90% ^b 80% ^b 100% ^b	-	-	60%	-	4/6 (66.7%)
195	40	319 (23.5) [0.113]	1 217 ^c 218	60% 60%	N/A ^c	-	40%	-	3/5
204	40	327 (22.7) [0.108]	200 116 210	90% ^b - -	-	5% 50%	-	N/A	3/5
208	40	328 (21.5) [0.103]	261 102 262	- - -	-	30%	-	-	1/6
210	40	307 (20.4) [0.105]	263 117 163 ^c	30%	-	-	-	-	1/6
									8/22 (36.4%)
200	45	292 (19.2) [0.099]	120 253 206 ^c	- - -	-	-	-	-	0/6
206	15	293 (19.0) [0.092]	220 109 208	- - -	-	20%	-	N/A	1/5
197	60	215 (12.4) [0.078]	205 163 202	- - -	-	-	-	-	0/6

^aPressure time was measured at 1-ft depths.

^bOssicles fractured or disrupted; otherwise intact.

^cNot assessable.

-Indicates eardrum intact.



Dog No. 205, Right Ear



Dog No. 253, Left Ear



Dog No. 218, Right Ear



Dog No. 218, Left Ear



Dog No. 215, Right Ear



Dog No. 215, Left Ear

Figure 9.--Dog eardrum and ossicular damage viewed from the middle ear.

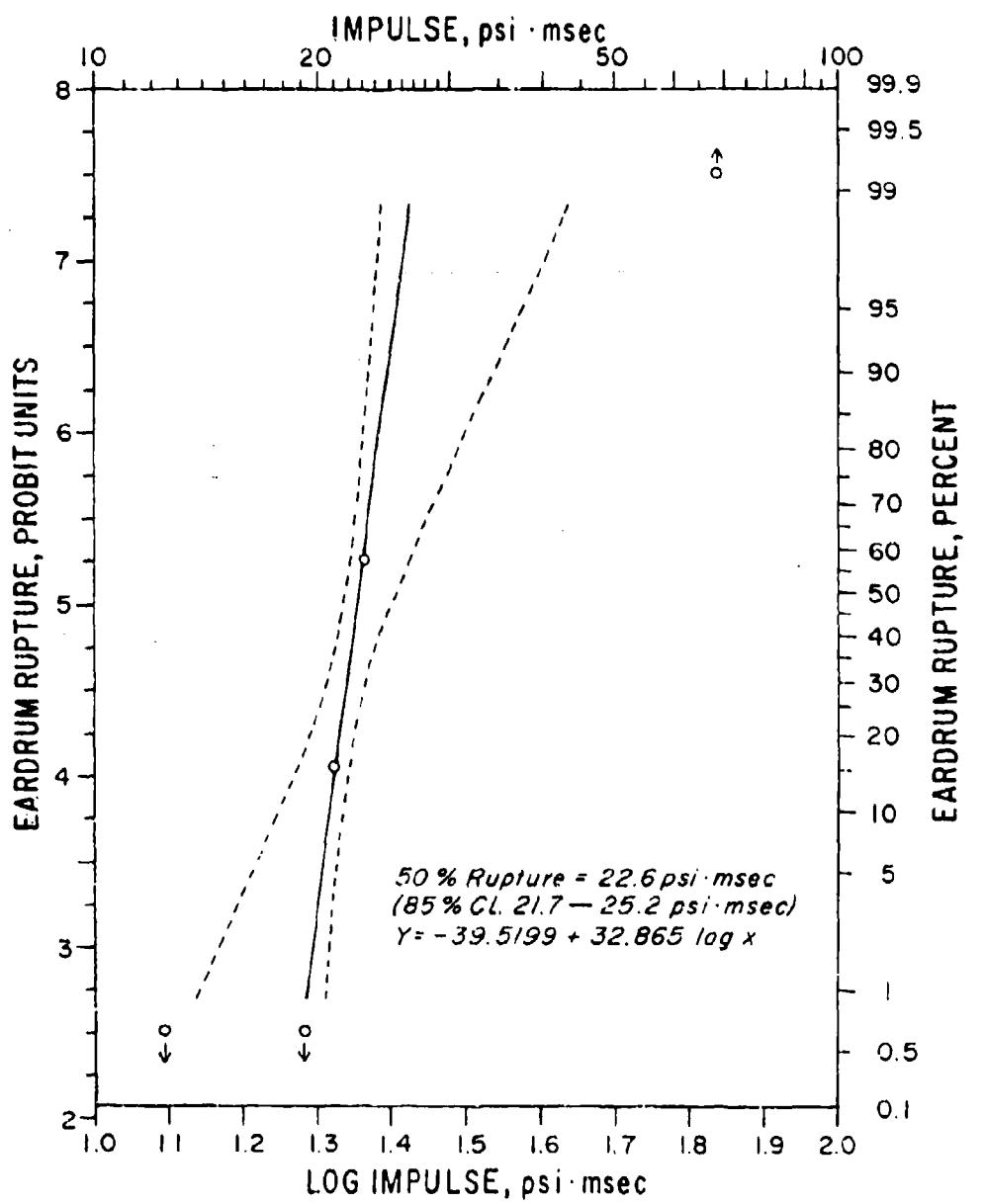


Figure 10.--Probit dose-response curve for the right ears of dogs.

for 4 minutes. No reason could be found for this malfunction. It was found that the life-support system could, in some instances, produce lung damage and hemorrhage in the lining of the middle ears and frontal sinuses. In addition, contusions of the endocardium were found in these subjects and in animals that received no blast. One of the animals placed at a 10-ft depth exhibited petechia about the anal sphincter. This lesion could be a result of placing the animal in a seated position. Hyperemic spots in the lining of the G.I. tract have been found in control sheep from other experiments in this facility. Histological examination revealed them to be caused by parasitic round worms. In some of the experimental sheep in the present study, hyperemic areas were assessed histologically and found to be associated with these parasitic round worms.

Pressure-Time Measurements

Incident Shock Waves

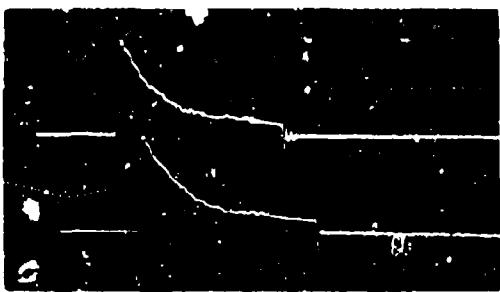
Pressure-time records showing the pattern of the incident shock waves, at selected ranges, are illustrated in figure 11. These records show that there is little to be desired from the NOL underwater-pressure gages which have the tourmaline crystals inside a Tygon^(R) tube filled with silicone oil. The values for peak pressure, impulse, energy, theta, and cutoff time for each pressure-time record are listed in tables B-1 through B-10 of appendix B. As already mentioned, these values were calculated by a computer. The mean values for peak pressure, impulse, and cutoff time measured at 1-ft depths on the 1-lb charge firings are plotted in figure 12 in relation to slant range. The curves in figure 12 are those calculated from these empirically derived equations:

$$P_m = 18300 \left(W^{1/3} / R \right) 1.10 \quad (1)$$

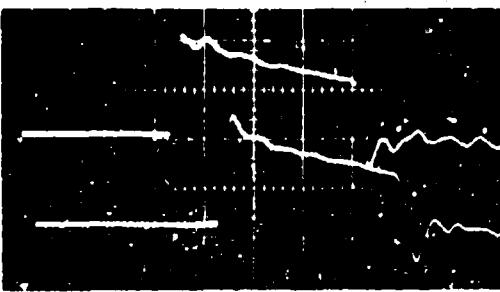
$$\theta = 0.0603 \left(W^{1/3} / R \right)^{-0.168} W^{1/3} \quad (2)$$

$$t_c = \left(R^2 + 4 D_w D_g - R \right) / C_0 \quad (3)$$

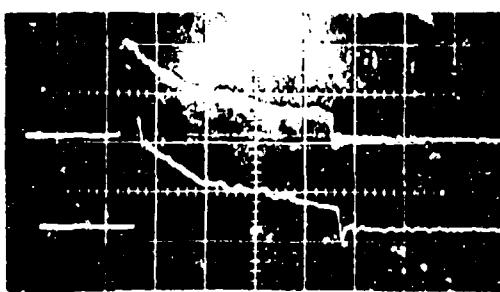
$$I = P_m \theta \left[\frac{9}{11} \left(1 - e^{-\frac{11t_c}{10\theta}} \right) + 1 - e^{-\frac{t_c}{10\theta}} \right] \quad (4)$$



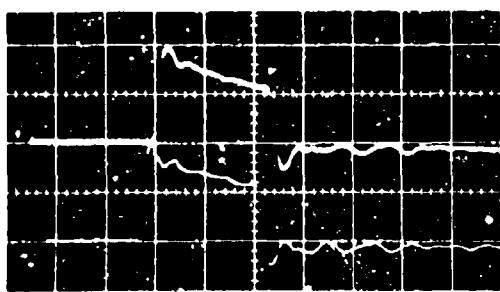
Shot No.: 188 Slant Range: 13 ft
 Gauge No. Vertical Scale Horiz. Scale
 3257 565 psi/div 0.1 msec/div
 3412 571 psi/div 0.1 msec/div



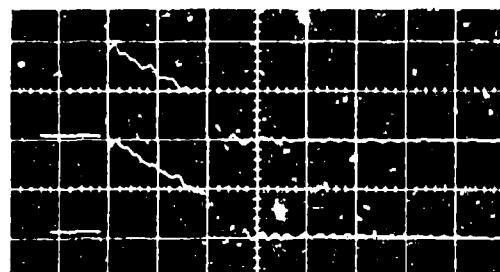
Shot No.: 199 Slant Range: 60 ft
 Gauge No. Vertical Scale Horiz. Scale
 3414 100 psi/div 0.02 msec/div
 3264 100 psi/div 0.02 msec/div



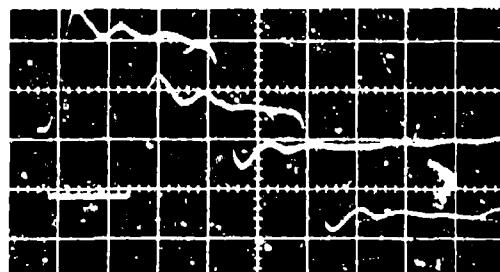
Shot No.: 201 Slant Range: 20 ft
 Gauge No. Vertical Scale Horiz. Scale
 3114 320 psi/div 0.05 msec/div
 3264 330 psi/div 0.05 msec/div



Shot No.: 209 Slant Range: 78 ft
 Gauge No. Vertical Scale Horiz. Scale
 3257 75 psi/div 0.02 msec/div
 3412 73 psi/div 0.02 msec/div



Shot No.: 204 Slant Range: 40 ft
 Gauge No. Vertical Scale Horiz. Scale
 3257 153 psi/div 0.05 msec/div
 3412 158 psi/div 0.05 msec/div



Shot No.: 193 Slant Range: 130 ft
 Gauge No. Vertical Scale Horiz. Scale
 3257 43 psi/div 0.01 msec/div
 3412 41 psi/div 0.01 msec/div

Figure 11. Oscillograms of incident shock waves from 1-lb charges at 10-ft depths recorded by gages at 1-ft depths.

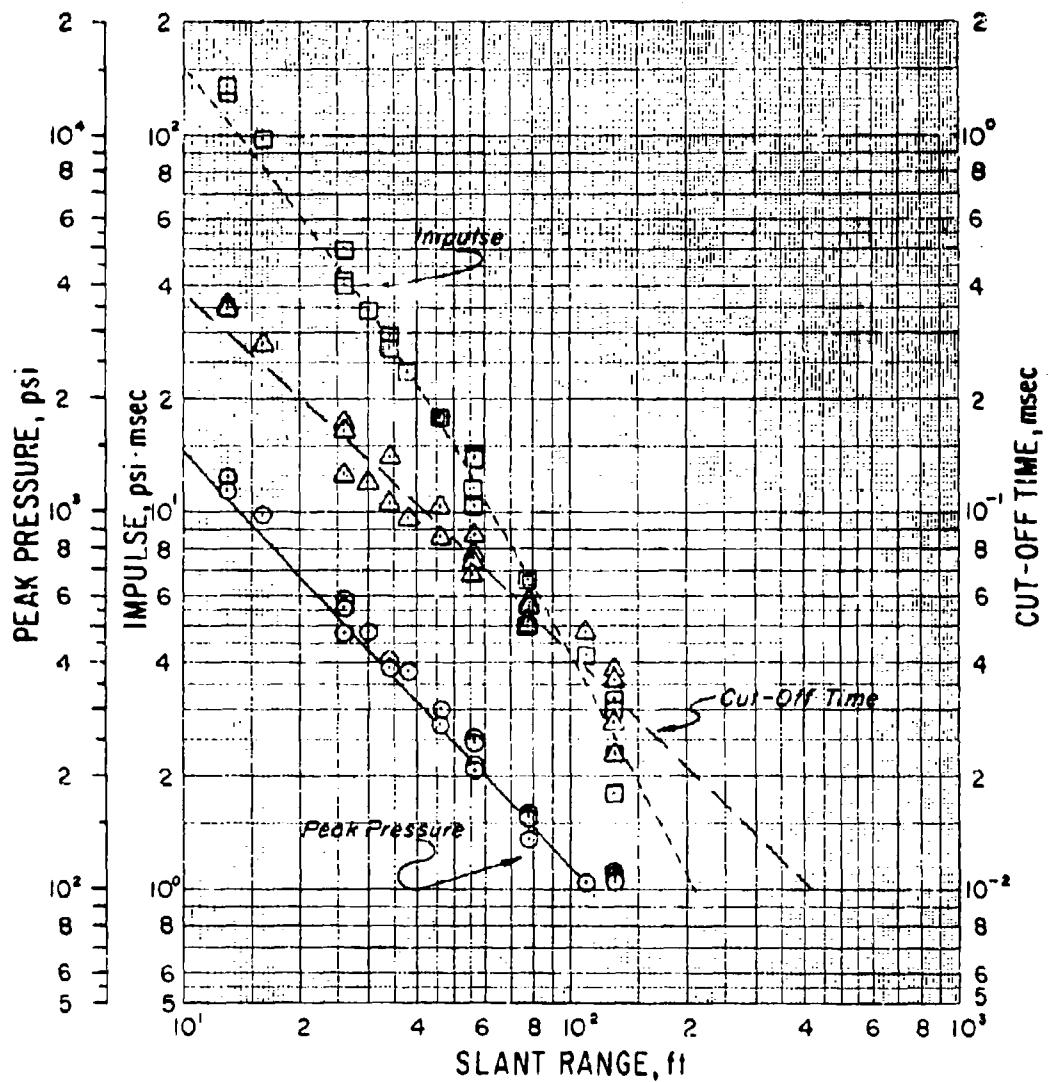


Figure 12. --Pressure-time parameters in the incident shock wave at 1-ft depths as a function of range from 1-lb charges detonated at 10-ft depths. [The data points were measured; the curves were computed.]

where W = charge mass, lb; R = slant range, ft; t_c = time of arrival of the surface cutoff wave, msec; θ = time constant, msec; P_m = peak overpressure, psi; I = impulse to cutoff time, psi·msec; D_w = depth of charge, ft; D_g = depth of gage, ft; and C_0 = speed of sound in water, 4.75 ft/msec.

As seen in figure 12 the measured data points for peak pressure, impulse, and cutoff time fall closely along the calculated curves. Moreover, there was little variation in the values measured by different gages, on a given shot, in regard to peak pressure, impulse, and cutoff times, tables B-1 through B-10 appendix B.

Negative Pressures

The peak negative pressures measured in the incident shock wave appear in tables B-1 through B-10 in appendix B. The peak negative pressures were read from the records from the preshock baseline to the maximum deflection the trace went below baseline. The mean peak negative pressures on each shot are plotted in figure 13 in relation to scaled slant range. The magnitude of the negative pressures decreased with increasing slant range. They ranged from 110 to 150 psi at scaled ranges of 13 and 16 ft to 20 to 25 psi at scaled ranges of 140 ft. The negative pressures were of short duration-on the order of $10 \mu\text{sec}$, which, in terms of the frequency response of gages, could account for some of the scatter in these measurements. There was fair agreement between the points measured in this study and the curve for tap water from reference 8. The curves were obtained by measuring with piezoelectric gages the tension in the reflected wave in a vertical pipe filled with water. The bottom of the pipe contained a piston that was driven by a lead bullet fired at its center. The upper end of the pipe was open. The results showed that, the greater the pressure in the incident wave, the greater was the tension in the reflected wave, with maximum values in the tension wave leading off at 8.5 atmospheres for tap water and 15 atmospheres for boiled deionized water.

Bottom Reflections

A limited number of measurements were made of the waves that reflected from the bottom of the pond. The waveforms of these bottom reflections, recorded by gages at 1-ft depths on 1-lb charge firings, are illustrated in figure 14. As seen in the figure, the reflected waves recorded over the 13- to 45-ft

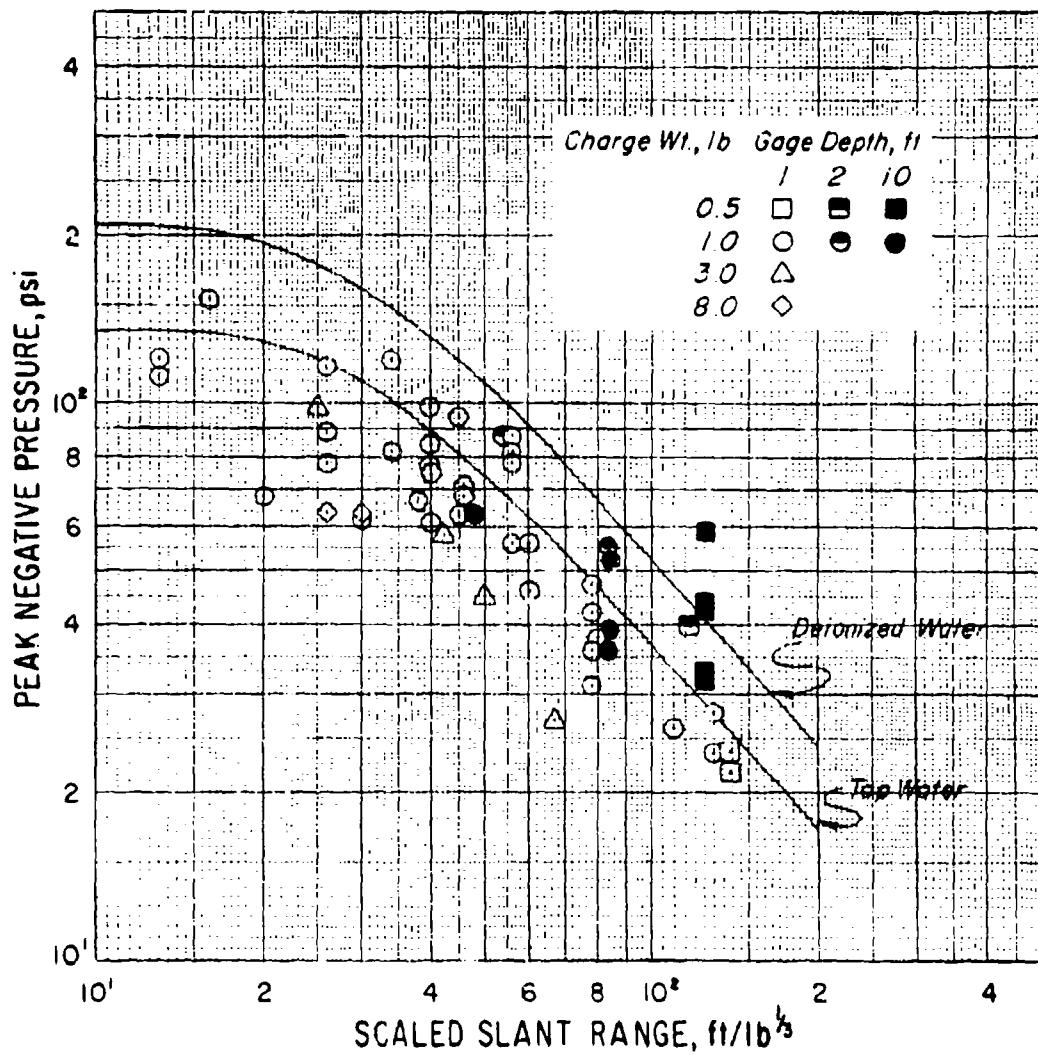
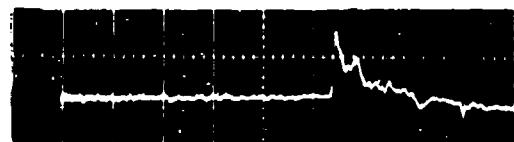


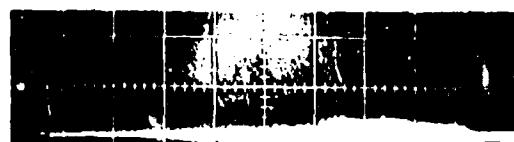
Figure 13.--Peak negative pressures as a function of scaled range from charges detonated at 10-ft depths. [The data points were measured; the curves were taken from reference 8.]



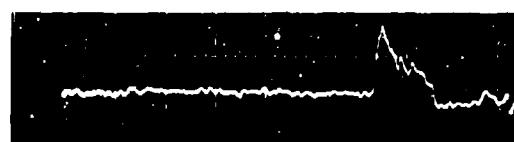
Shot No.: 188 Scale:
Gauge No.: 3414 Vertical: 583 psi/div
Slant Range: 13 ft Horiz.: 2.0 msec/div



Shot No.: 205 Scale:
Gauge No.: 3264 Vertical: 124 psi/div
Slant Range: 56 ft Horiz.: 0.1 msec/div



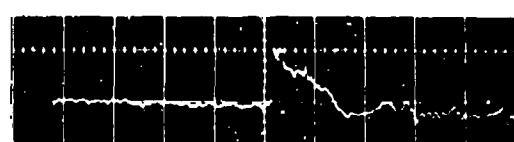
Shot No.: 189 Scale:
Gauge No.: 3414 Vertical: 450 psi/div
Slant Range: 16 ft Horiz.: 2.0 msec/div



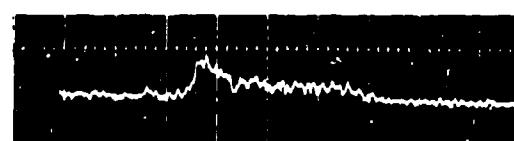
Shot No.: 199 Scale:
Gauge No.: 3264 Vertical: 92 psi/div
Slant Range: 66 ft Horiz.: 0.1 msec/div



Shot No.: 194 Scale:
Gauge No.: 3257 Vertical: 243 psi/div
Slant Range: 20 ft Horiz.: 2.0 msec/div



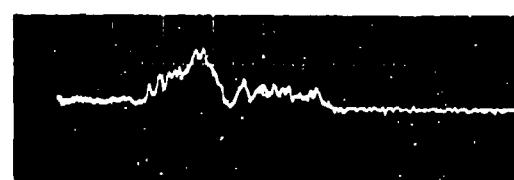
Shot No.: 199 Scale:
Gauge No.: 3412 Vertical: 89 psi/div
Slant Range: 66 ft Horiz.: 0.1 msec/div



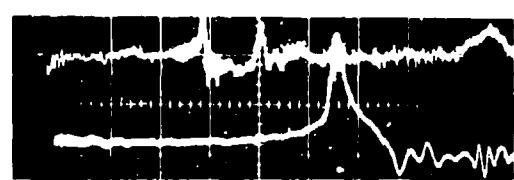
Shot No.: 196 Scale:
Gauge No.: 3264 Vertical: 145 psi/div
Slant Range: 40 ft Horiz.: 0.1 msec/div



Shot No.: 201 Scale:
Gauge No.: 3264 Vertical: 62 psi/div
Slant Range: 80 ft Horiz.: 0.1 msec/div



Shot No.: 200 Scale:
Gauge No.: 3264 Vertical: 109 psi/div
Slant Range: 45 ft Horiz.: 0.1 msec/div



Shot No.: 193 Scale:
Gauge No.: 3264 Vertical: 43 psi/div
Slant Range: 130 ft Horiz.: 0.05 msec/div

Figure 14.--Oscillograms of bottom reflected waves recorded by gages at 1-ft depths when 1-lb charges were detonated at 10-ft depths.

ranges were altered markedly from the ideal form that could be expected. The peak pressures were not on the leading portion of the waves. At and beyond the 60-ft range, the reflected waves appeared more normal in their pattern. Figure 15 gives the measured peak pressures and impulses in the bottom reflections along with the calculated curves. The peak pressure in the bottom reflected waves can be seen to be well below the calculated curves within the 45-ft range. Beyond 45 ft they were more near the curves. Measured impulses were an order of magnitude below the theoretical curve.

In contrast to peak pressure and impulse, the time between the incident and reflected shock waves and the cutoff times for the reflected wave were in fair agreement with the calculated curves, figure 16. The time between shocks ranged from near 10 msec at the closest range, down to 1.0 to 1.5 msec at the 130-ft range.

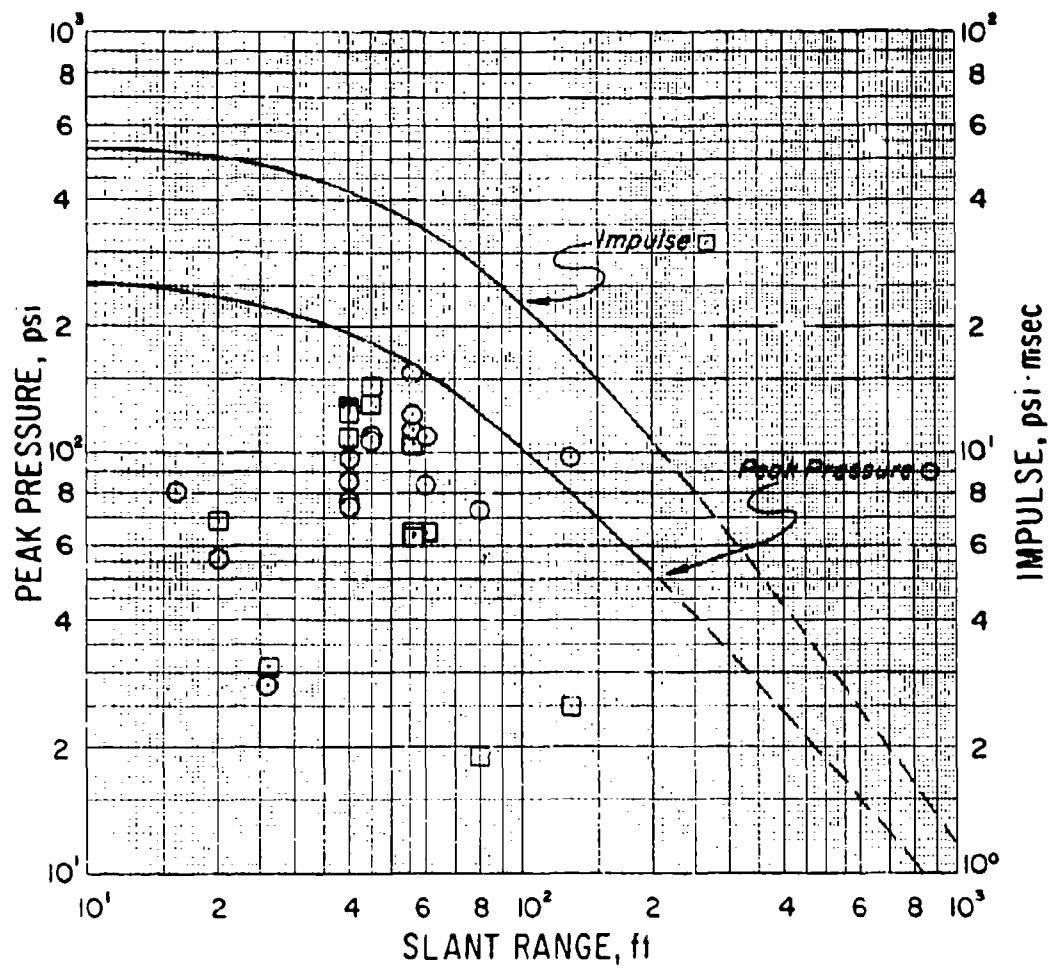


Figure 15.--Peak pressure and impulse in bottom reflected waves at 1-ft depths as a function of range from 1-lb charges detonated at 10-ft depths. [The data points were measured; the curves were computed.]

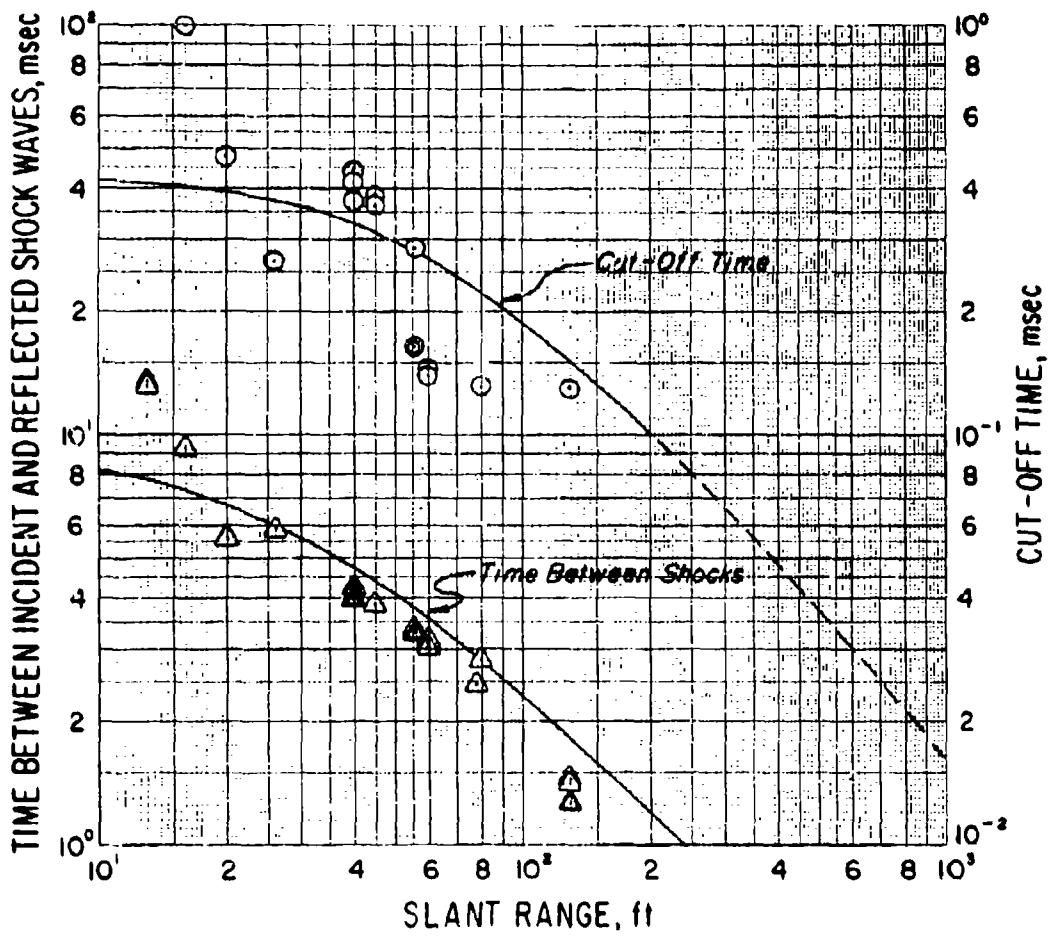


Figure 16. --Cutoff time for bottom reflected waves and time between the incident and reflected shock waves at 1-ft depths as a function of range from 1-lb charges detonated at 10-ft depths. [The data points were measured; the curves were computed.]

DISCUSSION

Safe Conditions From Underwater Explosions

This study has demonstrated how underwater-blast injuries fall off with range from small charges and has correlated these injuries and absence of injuries with the impulse parameter. This information well may be applied to establishing safe impulse levels (range^a) for swimmers in the environment of small underwater explosions. The results also may be applied to larger charge weights, provided swimmers are near the surface wherein the duration of the wave is governed more by the cutoff time than by charge weight. The results of this study also are helpful in establishing safe ranges because the results overlap animal data with volunteer swimmers.

According to the results of this study, large animal specimens did not receive any underwater-blast lesions at impulses of 1.8 to 3.0 psi·msec associated with peak pressures of 106 to 111 psi while at the 130-ft range from 1-lb charges with their heads out of the water. Thus, an impulse of 2 to 3 psi·msec, associated with a peak pressure on the order of 100 psi, apparently is a sure-safe underwater-blast dose for unprotected swimmers with their head out of the water. That these are a safe set of conditions for man, also, was confirmed by a volunteer swimmer, who was at the 130-ft range in the present study along with the sheep on Shot 193. The volunteer, clad only in swim trunks, was oriented vertically in the water immersed to his chin. He was face-on to the charge with arms outstretched to the side. The subject felt only one pulse in the form of some slight pressure over a 4- to 5-in diameter with a transient inward movement of the abdominal wall area around his navel which was approximately 1.5 ft beneath the water surface. Nothing was felt on other body regions. On the three preceding tests with 1-lb charges 60 ft from the west end of the pond, the volunteer was standing in the water at the southeast corner of the pond, a horizontal range of about 165 ft. The only sensation experienced from the underwater blast was a mild sting-like effect-like getting poked with the sharp end of a thumb tack. The effect was felt only at one point on the body: between the knees and ankles while in water 2.5-ft deep, between the hips and knees in water 3.5-ft

deep, and at the lower abdomen while in water 5-ft deep (neck deep). Other pertinent information regarding unprotected swimmers is reported in reference 2. Volunteer swimmers wearing just swim trunks approached 110-lb charges at decreasing ranges where the calculated pressures were 22.5 psi to 69.2 psi and only experienced slight abdominal sensations with no feeling of impact on the thorax. The 110-lb charge was detonated at a 3-ft depth. The swimmers were in shallow water 5-ft deep with a soft mud bottom. On another occasion, with conditions paralleling the aforementioned ones, the volunteer was at 140 psi. The impulse levels were not given but were calculated to be 0.0128 psi·msec associated with 22 psi, 0.114 psi·msec for 69 psi, and 0.440 psi·msec for 140 psi. Unfortunately, the impulses were very low because the cutoff times were so short (0.58, 1.65, and 3.14 μ sec) due to shallow burst depths and relatively long ranges.

Since blast lesions were rare in animals that received less than 10 psi·msec, the nondamaging impulse for man is probably higher than 2 to 3 psi·msec, but until more investigations are carried out, one would hesitate to predict the higher impulse levels that could be tolerated by unprotected swimmers. The underwater-blast impulse levels that humans could tolerate may depend on such factors as the amount, size, and distribution of metabolic gas bubbles in the G.I. tract. These factors could explain why the data suggest that the dog can tolerate higher impulse levels than the sheep without sustaining abdominal lesions.

Ear Injury

The authors are unaware of any information in the literature on eardrum rupture from underwater blast that could be compared with that from the present study. According to the results from the dogs, one would not expect eardrum rupture in swimmers with heads immersed at 2 to 3 psi·msec impulse levels. How obnoxious the sound intensity would be to a person at that impulse level can not be stated at this time.

The severity of ear injury encountered in the dogs tested at the 40-ft range could be important in terms of safety. At the 40-ft range (impulse 20.4 to 23.5 psi·msec), the ear injury was probably as serious an injury as the lung or G.I. tract injuries. At that range, half the dogs sustained eardrum rupture. When water enters the middle ear, especially unilaterally, it seriously disturbs man's

sense of equilibrium. Obviously, this is a condition undesirable for someone swimming beneath the water's surface.

Bottom Reflections

There are several reasons why bottom reflections encountered in the test pond were not significant in regard to adding to the underwater-blast dose that the animals received.

First, based on the response of animals to air blasts having various waveforms (reference 9), the aberrant waveform of the bottom reflection over the ranges out to approximately 45 ft would not be expected to produce damage. Even though these impulses appear rather high in some instances, 10 to 15 psi·msec, the associated peak pressures were low, and the peak pressure was not at the leading edge of the wave. Beyond 71 ft, the waves are more ideal-like, but the peak pressures are low, and, more importantly, the pulses are of short duration so that the impulses are small.

Second, if the bottom reflections were to add to the incident blast-wave dose, one could expect to find a rise in the incidence of injuries at ranges that correspond to those where the reflected pressure waves are greater. That is, from 40 to 60 ft the pressure and impulse in the bottom reflections were the highest, yet the biological effects decreased over those ranges for targets at the 1-ft depths.

Third, some unpublished information exists in this laboratory that suggests that two pulses do not add to the damage effect unless they are delivered within a very short time--less than 2 msec. Furthermore, if these pulses are of low intensity, they are not additive even if delivered within the critical time. In order to have an additive effect from two pulses, they must be near lethal levels to begin with.

The reason that the bottom reflections are altered markedly from their classical waveforms cannot be given at this time. This effect is probably associated with the reflected wave having to travel through the bubble pulse and surrounding disturbed water, cavitation of the water, nature of the bottom, its angle of incident to the bottom, etc. Whatever the reason, it is beneficial not to have a strong reflection from the bottom in this test pond.

Negative Pressures

Although the biological effects correlated reasonably well with the impulse delivered by the underwater blast wave, the impulse may not necessarily be the exact damage parameter. It is not clear at this time whether or not the negative pressure could have something to do with the damage mechanism. If the negative pressure plays a part, one would expect the biological effects to correlate with some parameter(s) of the negative part of the pressure-time curve. This study was not designed to elucidate the damage mechanisms that must await future investigations.

Targets Horizontal to the Surface

The results of the tests run with animals horizontal to the surface suggest that the impulse necessary to inflict G.I. tract damage may not be much different from that necessary to cause lung hemorrhage. It has been stated repeatedly in the literature, for instance reference 10, that for personnel near the surface the impulse delivered to the deeper portions of the body is greater than that received by those closer to the surface. Consequently, for targets upright in the water at a given range from an underwater explosion, one would expect the abdominal lesions to be more severe than those in the thorax. However, for animals horizontal to the surface, there is little difference in the damage to these body regions. In this connection, the information obtained on the tests run with animals at 0.5-ft depths demonstrates well that a swimmer in the vicinity of an underwater explosion is far safer if he is attempting to get horizontal to the surface and as far out of the water as possible than if he is treading water; the difference in orientation could mean the difference between lethal and nonlethal blast injuries. One could not conclude from the limited amount of data whether or not the prone or supine orientation affords more protection from the underwater blast.

RECOMMENDATIONS

1. Perform tests to determine the effect of bubble size and distribution of metabolic gas on injury to the G.I. tract from underwater explosions.
2. Obtain pressure-time measurements inside animals during underwater-blast exposure. This should aid in understanding the mechanisms of underwater-blast damage and in developing a general damage model.
3. Investigate the possibility of using special clothing and ear protectors to reduce the severity of minor immersion-blast injuries.
4. Evaluate the sound effects produced by underwater explosions from small charges in the very far-field with animals and/or volunteer swimmers.

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APPENDIX A
PATHOLOGY TABLES

Table A-1.--Effects of 0.5-lb charge fired at 10-ft depths on sheep at 1-ft depths.

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi·msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
181	110 (110)	89 ^a (3.1) [0.047]	136 (41)	No lung hemorrhage, (lung weight, 0.9%). No GI tract lesions; no blood clots in feces.
		81 ^b (4.5) [0.076]	143 (47)	No lung hemorrhage, (lung weight, 0.90%). No GI tract lesions; no blood clots in feces.
			129 (42)	No lung hemorrhage. (lung weight, 0.88%). No GI tract lesions; no feces.
182		88 ^a (3.0) [0.044]	138 (36)	No lung hemorrhage, (lung weight, 1.04%). No GI tract lesions; no feces.
		81 ^b (4.5) [0.076]	144 (33)	No lung hemorrhage, (lung weight, 1.22%). No GI tract lesions; no feces.
			130 (36)	No lung hemorrhage, (lung weight, 1.06%). No GI tract lesions, no feces.

^a Pressure time measured at 1-ft depths.
^b Pressure time calculated for 2-ft depths.

Table A-2.--Effects of 0.5-lb charge fired at 10-ft depths on sheep at 2-ft depths.

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi·msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
178	93 (93)	103 ^a (5.9) [0.091]	120 (40)	No lung hemorrhage, (lung weight, 0.88%). No GI tract lesions. Both eardrums intact.
		97 ^b (7.6) [0.135]	124 (32)	No lung hemorrhage, (lung weight, 1.04%). No GI tract lesions. Both eardrums intact.
			247 (56)	Petechial lung hemorrhage, (lung weight, 0.86%). Mild contusions of GI tract. Both eardrums intact.

^a Pressure time measured at 2-ft depths.
^b Pressure time calculated for 1-ft depths.

Table A-3.--Effects of 0.5-lb charge fired at 10-ft depths on targets at 10-ft depths.

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi-msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
180	100 (100)	93 ^a (12.1) [0.454]	D-121 (19)	No lung hemorrhage, (lung weight, 0.83%). No GI tract lesions. Both eardrums intact.
			D-122 (18)	Petechial lung hemorrhages, (lung weight, 0.86%). No GI tract lesions. Both eardrums intact.
			D-118 (20)	Petechial lung hemorrhages, (lung weight, 0.82%). No GI tract lesions. Both eardrums intact.
170		111 ^a (11.7) [0.372]	S-123 (34)	Petechial lung hemorrhages, (lung weight, 1.05%). Mild contusions. Both eardrums intact. No blood in feces.
			S-101 (37)	Petechial lung hemorrhage, (lung weight, 1.18%). No GI tract lesions. No blood in feces. Both eardrums intact.
			S-122 (36)	Petechial lung hemorrhage, (lung weight, 1.00%). No GI tract lesions. Left eardrum ruptured, right eardrum intact.
169		92 ^a (11.5) [0.400]	S-108 (38)	No lung hemorrhage, (lung weight, 0.86%). No GI tract lesions; no feces. Right eardrum ruptured, left eardrum intact.
(continued)				

Table A-3.--(Continued).

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi-msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
169 (con.)			S-121 (41)	Lungs discolored, ^b (lung weight, 1.30%). No GI tract lesions. Both eardrums intact.
			S-114 (40)	Lungs discolored, ^b (lung weight, 1.32%). No GI tract lesions. Both eardrums intact.
166	100 (100)	97 ^a (11.2) [0.382]	S-237 (50)	Petechial lung hemorrhage, (lung weight, 0.82%). Hyperemic spot in rectum, no feces. Both eardrums intact.
			S-55 (50)	Petechial lung hemorrhages, (lung weight, 0.83%). No GI tract lesions; no feces. Both eardrums intact.
			S-49 (48)	Petechial lung hemorrhages, (lung weight, 1.05%). Mild contusions of G.I. tract. No feces. Both eardrums intact.

^a Pressure time measured at 10-ft depths.
^b Sheep died-drowned or asphyxiated.

Table A-4. --Effects of 1-lb charge fired at 10-ft depths on targets at 1-ft depths.

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
152	26 (24)	478 ^a (41.5) [0.166]	D-224 (20)	Slight lung hemorrhage, (lung weight, 0.76%). Mild contusions of GI tract; no blood in feces.
		508 ^b (55.6) [0.315]	M-76 (6)	Slight lung hemorrhage, (lung weight, 0.68%). Contusions of GI tract; blood clots in feces.
136		563 ^a (40.6) [0.127]	S-156 (41)	Petechial lung hemorrhage, (lung weight, 1.02%). Contusions of GI tract; blood clots in feces.
		508 ^b (55.6) [0.315]	S-185 (37)	No lung hemorrhage, (lung weight, 1.04%). Contusions of GI tract; blood clots in feces.
			S-189 (42)	No lung hemorrhage, (lung weight, 0.78%). Contusions of GI tract; blood clots in feces.
137	30 (29)	481 ^a (34.7) [0.121]	S-169 (38)	No lung hemorrhage, (lung weight, 1.16%). Contusions of GI tract; blood clots in feces.
		434 ^b (46.2) [0.275]	S-118 (38)	No lung hemorrhage, (lung weight, 0.94%). Contusions of GI tract; blood clots in feces.
			S-167 (41)	No lung hemorrhage, (lung weight, 0.89%). Contusions of GI tract; blood clots in feces.
(continued)				

Table A-4.--(Continued).

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi·msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
151	34 (33)	389 ^a (29.7) [0.140]	M-80 (5.6)	No lung hemorrhage, (lung weight, 0.57%). Contusions of GI tract; blood clots in feces.
		378 ^b (39.1) [0.244]	D-208 (21)	No lung hemorrhage, (lung weight, 0.72%). Contusions of GI tract; no feces.
138		407 ^a (27.5) [0.107]	S-171 (41)	No lung hemorrhage, (lung weight, 0.94%). Contusions of GI tract; blood clots in feces.
		378 ^b (39.1) [0.244]	S-115 (36)	No lung hemorrhage, (lung weight, 0.91%). Mild contusions of GI tract; no feces.
			S-116 (37)	No lung hemorrhage, (lung weight, 0.97%). Mild contusions of GI tract; no feces.
139	38 (37)	381 ^a (23.9) [0.219]	S-NN (38)	No lung hemorrhage, (lung weight, 0.99%). Mild contusions of large intestine, contusions and petechia in rectum; blood clots in feces.
		335 ^b (33.6) [0.219]	S-158 (39)	No lung hemorrhage, (lung weight, 1.27%). Mild contusions of GI tract; no feces.
			S-177 (37)	No lung hemorrhage, (lung weight, 1.05%). Contusions of GI tract; no feces.
(continued)				

Table A-4.--(Continued).

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi-msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
141	46 (45)	306 ^a (18.2) [0.086]	S-165 (40)	No lung hemorrhage, (lung weight, 0.87%). Mild contusions on large intestine and "hyperemic" spot in rectum; no feces.
		271 ^b (25.5) [0.181]	S-191 (36)	No lung hemorrhage, (lung weight, 0.81%). Petechia in rectum; no feces.
			S-188 (37)	No lung hemorrhage, (lung weight, 0.83%). No GI tract lesions; no feces.
151		274 ^a (18.2) [0.104]	D-207 (18)	No lung hemorrhage, (lung weight, 0.83%). Mild contusions of GI tract; no feces.
		271 ^b (25.5) [0.181]	M-43 (4)	No lung hemorrhage, (lung weight, 0.64%). Petechia in GI tract; no feces.
179	56 (55)	246 ^a (14.2) [0.087]	D-213 (21)	No lung hemorrhage, (lung weight, 0.79%). No GI tract lesions.
		218 ^b (9.0) [0.149]	D-212 (21)	No lung hemorrhage, (lung weight, 0.83%). No GI tract lesions.
			D-161 (24)	No lung hemorrhage, (lung weight, 1.02%). No GI tract lesions.
(continued)				

Table A-4.--(Continued).

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi·msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
203	56 (55)	253 ^a (14.0) [0.078]	D-116 (20)	No lung hemorrhage, (lung weight, 0.82%). No GI tract lesions.
		218 ^b (19.0) [0.149]	D-200 (19)	No lung hemorrhage, (lung weight, 0.88%). No GI tract lesions.
			D-210 (20)	No lung hemorrhage, (lung weight, 0.84%). No GI tract lesions.
205		218 ^a (11.7) [0.077]	D-220 (14)	No lung hemorrhage, (lung weight, 0.88%). No GI tract lesions.
		218 ^b (19.0) [0.149]	D-210 (14)	No lung hemorrhage, (lung weight, 0.81%). No GI tract lesions.
			D-208 (14)	No lung hemorrhage, (lung weight, 0.98%). Focal mucosal hemorrhage in area of ileocecal valve.
153		200 ^a (11.0) [0.080]	D-221 (21)	No lung hemorrhage, (lung weight, 0.84%). No GI tract lesions; no feces.
		218 ^b (19.0) [0.149]	M-84 (5.9)	No lung hemorrhage, (lung weight, 0.48%). Hyperemic spots near anus; no feces.

(continued)

Table A-4.--(Continued).

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi·msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
145	56 (55)	207a (10.4) [0.068]	S-212 (46)	No lung hemorrhage, (lung weight, 0.85%). Few petechia at anus; no feces.
		218b (19.0) [0.149]	S-217 (46)	No lung hemorrhage, (lung weight, 0.91%). Small hyperemic area in rectum; blood clots in feces.
			S-211 (43)	No lung hemorrhage, (lung weight, 0.89%). Few petechia at anus; no blood clots in feces.
207	78 (78)	160a (6.6) [0.057]	D-261 (20)	No lung hemorrhage, (lung weight, 0.87%). No GI tract lesions.
		152b (11.1) [0.108]	D-102 (15)	No lung hemorrhage, (lung weight, 1.22%). No GI tract lesions.
			D-262 (19)	No lung hemorrhage, (lung weight, 0.87%). No GI tract lesions.
147		156a (6.6) [0.053]	S-228 (36)	No lung hemorrhage, (lung weight, 0.88%). No GI tract lesions; no blood clots in feces.
		152b (11.1) [0.108]	S-162 (37)	No lung hemorrhage, (lung weight, 0.99%). No GI tract lesions; no blood clots in feces.
			S-199 (39)	No lung hemorrhage, (lung weight, 0.77%). Mild contusion in cæcum; no blood in feces.
(continued)				

Table A-4.--(Continued).

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi-msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
154	78 (78)	157 ^a (6.2) [0.055]	D-216 (21)	No lung hemorrhage, (lung weight, 0.75%). No GI tract lesions; no feces.
		152 ^b (11.1) [0.108]	M-85 (4.6)	No lung hemorrhage, (lung weight, 0.56%). No GI tract lesions; no feces.
209		136 ^a (5.0) [0.050]	D-263 (19)	No lung hemorrhage, (lung weight, 1.05%). No GI tract lesions.
		152 ^b (11.1) [0.108]	D-117 (14)	No lung hemorrhage, (lung weight, 1.41%). No GI tract lesions except for few pin-head size spots in rectum.
			D-163 (14)	No lung hemorrhage, (lung weight, 1.62%). No GI tract lesions.
155 ^{a,c}	110 (110)	104 ^a (4.2) [0.048]	D-0 (16)	No lung hemorrhage, (lung weight, 0.89%). No GI tract lesions.
		104 ^b (6.1) [0.076]	M-33 (3.4)	No lung hemorrhage; (lung weight, 0.63%). No GI tract lesions.
156 ^{a,c}		104 ^a (4.2) [0.048]	S-193 (36)	No lung hemorrhage; (lung weight, 0.85%). No GI tract lesions.
		104 ^b (6.1) [0.076]	S-172 (39)	No lung hemorrhage; (lung weight, 0.92%). No GI tract lesions.
			S-222 (36)	No lung hemorrhage; (lung weight, 0.90%). No GI tract lesions.
(continued)				

Table A-4.--(Continued).

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi·msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
192	130 (130)	111 ^a (3.2) [0.038]	S-71 (46)	No lung hemorrhage, (lung weight, 0.83%). No GI tract lesions; no feces.
		87 ^b (4.5) [0.065]	S-70 (45)	No lung hemorrhage, (lung weight, 0.89%). No GI tract lesions; no feces.
			S-72 (47)	No lung hemorrhage, (lung weight, 0.97%). No GI tract lesions; no feces.
193		108 ^a (3.0) [0.036]	S-73 (46)	No lung hemorrhage, (lung weight, 0.85%). No GI tract lesions; no feces.
		87 ^b (4.5) [0.065]	S-74 (45)	No lung hemorrhage, (lung weight, 0.86%). No GI tract lesions; no feces.
			S-75 (45)	No lung hemorrhage, (lung weight, 0.70%). No GI tract lesions; no feces.
190		106 ^a (2.3) [0.028]	S-66 (49)	No lung hemorrhage, (lung weight, 0.76%). No GI tract lesions; no feces.
		87 ^b (4.5) [0.065]	S-64 (45)	No lung hemorrhage, (lung weight, 0.80%). No GI tract lesions; no feces.
			S-65 (50)	No lung hemorrhage, (lung weight, 0.88%). No GI tract lesions; no feces.
(continued)				

Table A-4.--(Continued).

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi·msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
191	130 (130)	110 ^a (1.8) [0.023] 87 ^b (4.5) [0.065]	S-67 (50) S-68 (50) S-69 (47)	No lung hemorrhage, (lung weight, 0.87%). No GI tract lesions; no feces. No lung hemorrhage, (lung weight, 0.76%). No GI tract lesions; no feces. No lung hemorrhage, (lung weight, 0.85%). No GI tract lesions; no feces.

^a Pressure time measured at 1-ft depths.
^b Pressure time calculated for 2-ft depths.
^c Pressure-time values taken from shot no. 158.

Table A-5.--Effects of 1-lb charge fired at 10-ft depths on sheep at 2-ft depths.

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi-msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
175	33 (32)	436 ^a (44.4) [0.236]	S-102 (37)	Slight lung hemorrhage, (lung weight, 1.27%). Contusions of GI tract, petechia in rectum; blood clots in feces. Both eardrums ruptured.
		391 ^b (46.2) [0.373]	S-116 (41)	Slight lung hemorrhage, (lung weight, 0.97%). Contusions of GI tract, no feces. Right eardrum ruptured, left eardrum not readable.
			S-104 (34)	Extensive lung hemorrhage, (lung weight, 1.45%). Contusions of GI tract, no ulceration; blood clots in feces. Right eardrum intact, left eardrum not readable.
176	54 (53)	259 ^a (21.9) [0.160]	S-106 (36)	Petechial lung hemorrhage, (lung weight, 0.94%). No GI tract lesions. Eardrums intact.
		227 ^b (24.2) [0.232]	S-107 (34)	Petechial lung hemorrhage (lung weight, 1.03%). No GI tract lesions. Eardrums intact.
			S-111 (34)	Petechial lung hemorrhage, (lung weight, 1.10%). Few petechia in rectum. Right eardrum intact, left eardrum not readable.
(continued)				

Table A-5.--(Continued).

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi-msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
177	83 (83)	150 ^a (9.7) [0.101]	S-118 (43)	Petechial lung hemorrhage, (lung weight, 0.90%). No GI tract lesions. Both eardrums intact.
		142 ^b (12.8) [0.152]	S-50 (40)	Petechial lung hemorrhage, (lung weight, 0.74%). No GI tract lesions. Both eardrums intact.
			S-119 (33)	No lung hemorrhage, (lung weight, 0.91%). No GI tract lesions. Both eardrums intact.

^a Pressure time measured at 2-ft depths.
^b Pressure time calculated for 3-ft depths.

Table A-6. --Effects of 1-lb charge fired at 10-ft depths on sheep at 10-ft depths.

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi-msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
168	48 (48)	269 ^a (45.5) [0.809]	S-103 (42)	Slight lung hemorrhage, (lung weight, 0.80%). Mild contusions and petechia in GI tract; no feces. Both eardrums intact.
			S-115 (41)	Slight lung hemorrhage, (lung weight, 0.90%). Mild contusions of GI tract; trace of blood in feces. Both eardrums intact.
			S-105 (40)	Slight lung hemorrhage, (lung weight, 1.26%). Mild contusions of stomach and small in- testine; scattered con- tusions of large intestine and rectum; no feces. Both eardrums intact.
167	84 (84)	153 ^a (22.8) [0.516]	S-113 (41)	Few petechial lung hemorrhage, (lung weight, 0.83%). No GI tract lesions. Both eardrums intact.
			S-148 (42)	Slight lung hemorrhage, (lung weight, 0.73%). Contusions of rectum; no feces. Both eardrums intact.
			S-117 (44)	No lung hemorrhage, (lung weight, 0.81%). Mild contusions of GI tract; no feces. Both eardrums intact.

(continued)

Table A-6.--(Continued).

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
171	84 (84)	166 ^a (21.7) [0.429]	S-110 (43) S-125 (41) S-109 (37)	Petechial lung hemorrhage, (lung weight, 0.89%). Mild contusions of GI tract; no feces. Both eardrums intact. Petechial lung hemorrhage, (lung weight, 0.90%). One contusion of caecum; no feces. Both eardrums intact. Petechial lung hemorrhage, (lung weight, 1.13%). Mild contusions of large intestine, no ulcerations; no feces. Eardrums not readable.

^a Pressure time measured at 10-ft depths.

Table A-7.--Effects of 3-lb charge fired at 10-ft depths on sheep at 1-ft depths.

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi·msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
143	36 (35)	538 a (40.3) [0.106]	S-179 (36)	Slight lung hemorrhage, (lung weight, 1.25%). Contusions of large intestine; blood clots in feces.
		532 b (64.4) [0.230]	S-173 (34)	Slight lung hemorrhage, (lung weight, 1.09%). Contusions of GI tract; no feces.
			S-97 (36)	Petechial lung hemorrhages, (lung weight, 1.02%). Contusions of GI tract; no feces.
144	61 (60)	299 a (15.9) [0.066]	S-201 (41)	No lung hemorrhage, (lung weight, 0.84%). No GI tract lesions; no feces.
		298 b (27.0) [0.137]	S-215 (45)	No lung hemorrhage, (lung weight, 0.88%). Single contusion of large intestine and rectum; no blood clots in feces.
			S-225 (43)	No lung hemorrhage, (lung weight, 0.84%). Scattered petechia in rectum; blot clots in feces.
146	72 (71)	248 a (11.8) [0.059]	S-214 (39)	No lung hemorrhage, (lung weight, 0.86%). Scattered petechia in rectum, no blood clots in feces.
(continued)				

Table A-7.---(Continued).

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi-msec) [Duration, msec]	Animal No. (Body) Wt., kg	Effects
146 (con.)			S-229 (42)	No lung hemorrhage, (lung weight, 0.94%). Scattered petechia in rectum; no blood in feces.
			S-224 (41)	No lung hemorrhage, (lung weight, 0.78%). Scattered petechia in rectum; blood clots in feces.
148	97 (97)	191 ^c (7.4) [0.047]	S-206 (39)	No lung hemorrhage, (lung weight, 0.99%). No GI tract lesions; no blood clots in feces.
		179 ^b (12.3) [0.087]	S-184 (39)	No lung hemorrhage, (lung weight, 1.04%). No GI tract lesions; no blood clots in feces.
			S-205 (39)	No lung hemorrhage, (lung weight, 0.87%). Few petechia in anus, no blood clots in feces.

^a Pressure time measured at 1-ft depths.
^b Pressure time calculated for 2-ft depths.
^c Pressure-time values taken from shot no. 150.

Table A-8. --Effects of 8-lb charge fired at 10-ft depths on sheep at 1-ft depths.

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi·msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
140	52 (51)	556 ^a (33.2) [0.074]	S-186 (36)	Slight lung hemorrhage, (lung weight, 1.07%). Contusions of GI tract; blood clots in feces.
		508 ^b (57.4) [0.161]	S-194 (37)	Slight lung hemorrhage, (lung weight, 0.91%). Contusions of GI tract; no feces.
			S-161 (36)	Slight lung hemorrhage, (lung weight, 0.92%). Contusions of GI tract; blood clots in feces.
142	60 (59)	477 ^a (26.4) [0.067]	S-187 (34)	No lung hemorrhage, (lung weight, 1.08%). Mild contusions of rectum; blood clots in feces.
		434 ^b (44.7) [0.140]	S-114 (34)	No lung hemorrhage, (lung weight, 1.11%). Contusions of GI tract; blood clots in feces.
			S-85 (37)	No lung hemorrhage, (lung weight, 0.73%). Contusions of GI tract; blood clots in feces.

^a Pressure time measured at 1-ft depths.
^b Pressure time calculated for 2-ft depths.

Table A-9. --Effects of 1-lb charge fired at 10-ft depth on targets at 1-ft depths horizontal to surface.

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi·msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
189	16 (13.2)	987 ^a (99.6) [0.281]	S-62 (43)	Extensive lung hemorrhage, (lung weight, 2.38%). Bloody froth at nares. Scattered light contusions with slight ulcerations of mucosal feces, no blood clots. Hemorrhage in tracheal wall.
			S-61 (46)	Slight lung hemorrhage, (lung weight, 0.87%). Subserosal extravasation in the caecum; no feces. Extensive hemorrhage in tracheal wall.
			S-63 (45)	Extensive lung hemorrhage, (lung weight, 1.34%). Bloody froth at nares. Multiple contusions with ulcerations of G. I. tract; no feces. Hemorrhage in tracheal wall.
183	26 (24)	588 ^a (50.6) [0.173]	S-141 (36)	Respiration normal. Petechial lung hemorrhage, (lung weight, 0.95%). A few small (1/8-1/4-in.) hypemic areas in the ansa terminalis. No feces.
			S-134 (34)	Respiration normal. Slight lung hemorrhage, (lung weight, 1.08%). Several mild contusions in the ansa terminalis. No feces.
			D-231 (16)	Respiration normal. Slight lung hemorrhage (lung weight, 0.91%). One small (1/8-in.) mild contusion in rectum. No feces.

^a Pressure time measured at 1-ft depths.

All animals were oriented prone in the water.

Table A-10.--Effects of 1-lb charge fired at 10-ft depths on targets at 0.5-ft depths.

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi-msec) (Duration, msec)	Animal No. (Body Wt., kg)	Effects
187	13 (10)	1147 ^a (132.6) [0.354]	S-55 (43) VRSC ^c	Extensive lung hemorrhage, (lung weight, 1.60%). Down; grunting respiration. Six ruptures of small intestine. Multiple large areas of submucosal contusions with ulcerations of mucosal lining throughout stomach, large and small intestine, and rectum. Frank blood from anus.
		1089 ^b (85.7) [0.157]	S-56 (49) Prone ^c	Slight lung hemorrhage (lung weight, 1.27%). Four one-inch segments of submucosal mild contusions in ansa terminalis and rectum. Feces; no hemorrhage.
			S-57 (43) Supine ^c	Extensive lung hemorrhage, (lung weight, 1.45%). Few half inch subserosal contusions and hyperemic areas in ansa terminalis. No ulcerations of mucosal lining. No feces.
188	13 (10)	1224 ^a (135.4) [0.358]	S-58 (48) Supine	Extensive lung hemorrhage, (lung weight, 1.49%). Two submucosal contusions with ulceration of mucosal lining and one small mild contusion in caecum. Petechia surrounding fecal pellets in ansa spiralis. Feces; no blood clots.
(continued)				

Table A-10.--(Continued).

Shot No.	Slant Range, ft (Horizontal Range, ft)	Pressure, psi (Impulse, psi-msec) [Duration, msec]	Animal No. (Body Wt., kg)	Effects
188 (continued)			S-59 ^c (50) Prone ^c	Extensive lung hemorrhage, (lung weight, 1.27%). Slight amount of bloody froth from nares. Small contusion on stomach, four 1/8-1/4-inch submucosal contusions on small intestine and scattered small areas of submucosal contusions throughout spiralis and ansa terminalis with pin-head size clots of blood in lumen.
			S-60 (49) Prone ^c	Extensive lung hemorrhage, (lung weight, 1.23%). Respiration slightly labored; slight amount of bloody froth from nares. Multiple small areas of subserosal contusions in small intestine. A 2-inch submucosal contusion in large colon and a few 1-inch submucosal contusions in ansa terminalis. No feces.

^a Pressure time measured at 1-ft depths.
^b Pressure time calculated for 0.5-ft depths.
^c Animal Orientations: VRSO - Animal mounted vertically in the water right-side-on (long axis perpendicular to surface). Supine - Animal mounted horizontally in the water, supine. Prone - Animal mounted horizontally in the water, prone.

Table A-11.--Lesions recorded in control animals.

Treatment	Animal No. ^a	Effects
None	S-250	All organs negative. Lung weight, 0.85%.
	S-112	Lungs negative; lung weight, 0.83%. 1/8-in ² hemorrhagic spot on mitral valve.
Placed on animal mounts on the grid and held at 1-ft depth.	S-190	All organs negative. Lung weight, 1.20%.
	S-112	All organs negative. Lung weight, 1.28%.
Placed on animal mounts on the grid and held at 10-ft depth for 4-min., no blast.	S-127	Died, water in face mask. Lungs discolored, many petechia. Lung weight, 2.02%. Hemorrhages beneath lining of middle ears.
	S-126	Died, no water in face mask. Lungs discolored. Lung weight, 1.75%. Middle ears negative.
	D-00	Sacrificed at 1 hr. Lungs negative. Lung weight, 0.94%. Two small subcapsular contusions in spleen. Hemorrhages beneath lining of middle ears.
	S-141	Air hungry. Many scattered petechia throughout lungs. Lung weight, 0.92%. Mild contusions in endocardium. Petechia at the anus. Petechia lining middle ears.
	S-228	Died. Lungs discolored, light colored hemorrhages. Lung weight, 2.07%. Petechia lining middle ears.
	S-69	Air hungry. Scattered petechia throughout lungs. Lung weight, 0.89%. Hemorrhages beneath lining of middle ears and frontal sinus. Contusions of endocardium.

^a S = sheep; D = dog.

APPENDIX B
PRESSURE-TIME PARAMETER TABLES

Table B-1.--Pressure-time parameters measured at 1-ft depths when 0.5-lb charges were detonated at 10-ft depths.

	Gauge No.	Range, ft Slant	Peak Pressure, psi	Impulse, psi·msec	Energy, in.·lb/in. ²	Cut-Off Time, msec	Theta, msec	Negative Pressure, psi	Time Interval Between Shocks, msec
181	3257	110	109.6	91	3.1	0.04	0.046	0.087	29
	3412		94	3.3	0.34	0.054	0.075	NR ^b	-
	3414		83	2.8	0.04	0.042	0.133	19	-
Mean			89	3.1	0.04	0.047	0.098	24	-
182	3264 ^a		20	1.0	0.003	0.122	-	-	2.000
	3257	110	109.6	95	3.2	0.04	0.045	0.076	29
	3412		94	3.2	0.04	0.047	0.064	18	-
Mean	3414		74	2.6	0.03	0.046	-	20	-
			88	3.0	0.04	0.044	0.070	22	-
	3264 ^a		7	0.7	0.001	0.356	-	-	1.967

^a Bottom reflection parameters.

^b Not readable.

Table B-2. --Pressure-time parameters measured at 2-ft depths when 0.5-lb charges were detonated at 10-ft depths.

Shot No.	Gauge No.	Range, ft	Peak Pressure, psi	Impulse, psi·msec	Energy, in.·lb/in. 2	Cut-Off Time, msec	Theta, msec	Negative Pressure, psi	Time Interval Between Shocks, msec
178	3257	93	92.7	105	6.0	0.08	0.091	0.090	43
	3412			111	6.5	0.09	0.097	0.092	42
	3414			94	5.2	0.07	0.085	0.097	34
Mean				103	5.9	0.08	0.091	0.093	40
	3264 ^a			33	0.5	0.002	0.054	-	2.174

^a Bottom reflection parameters.

Table B-3. --Pressure-time parameters measured at 10-ft depths when 0.5-lb charges were detonated at 10-ft depths.

Shot Gauge No.	Range, ft	Peak Pressure, psi	Impulse, psi-msec	Energy, in.-lb/in. ²	Cut-Off Time, msec	Theta, msec	Negative Pressure, ps;	Time Interval Between Shocks, msec
180	166	100	100	11.6	0.10	0.445	0.096	58
3257	100	86	86	12.8	0.10	0.455	0.129	58
3412		93	93	12.0	0.10	0.463	0.109	62
Mean			93	12.1	0.10	0.454	0.111	59
3264 ^a		36	1.2	0.003	0.247	-	-	0.685
170	100	100	11.3	11.4	0.12	0.370	0.093	32
3412		109	109	12.0	0.12	0.374	0.099	31
Mean			111	11.7	0.12	0.372	0.096	32
3264 ^a							-NRb-	
169	3257	100	94	11.9	0.10	0.416	0.112	48
3412		91	11.4	0.09	0.414	0.112	NR	-
3414		90	11.3	0.10	0.371	-	41	-
Mean		92	11.5	0.10	0.400	0.112	44	-
3264 ^a		47	0.7	3.004	0.055	-	-	1.429

Table B-3. --(Continued).

St. at N.,	Gauge No.	Range, ft	Peak Pressure, psi	Impulse, psi-nsec	Energy, in.·lb/lb, z	Cut-Off Time, msec	T.b.a. msec	Negative Pressure, psi	Time Interval Between Shocks, msec
									Plant Horiz.
169	3257	130	100	92	10.7	0.09	0.385	0.092	34
	3412		103	103	11.5	0.10	0.380	0.086	30
	3414		95	95	11.3	0.10	0.381	0.106	35
	Mean			97	11.2	0.10	0.382	0.095	33
3264 ^a			72	9.7	0.003	0.655	-	-	1.475
	135	270	106	96	10.3	0.09	0.339	0.069	12
	3264		96	96	11.7	0.10	0.351	0.104	45
Mean	3414		94	94	11.4	0.10	0.354	0.103	43
	3412 ^b		60	60	1.2	0.008	0.010	-	1.407

^a Bottom reflection parameters.^b Not readable.

Table B-4. -- Pressure-time parameters measured at 1-ft depths when 1-lb charges were detonated at 10-ft depths.

Set No.	Charge No.	Range, ft:		Peak Pressure, psi	Impulse, psi-msec	Energy, in.·lb/in. ²	Cut-Off Time, msec	Theta, msec	Negative Pressure, psi	Time Interval Between Shocks, msec
		Start	Horiz.							
1-1	3257	13	5.5	1227	132.5	14.07	0.355	0.097	122	-
	3412			1226	138.4	14.05	0.361	0.102	120	-
Mean				122+	135.4	14.36	0.758	0.100	121	-
1-2	3414 ^a			-	-	-	-	-	-	13.662
	3257	13	2	116.5	124.6	13.55	0.353	0.103	122	-
	3412			1126	135.5	13.64	0.354	0.113	103	-
Mean				114-	132.6	13.74	0.354	0.108	112	-
1-3	3257			-	-	-	-	-	-	13.364
	3412	14	13.2	97.0	56.5	6.62	0.277	0.103	149	-
				1063	102.7	9.54	0.285	0.102	157	-
Mean				98-	95.6	9.16	0.261	0.102	153	-
1-4	3414 ^a			82	-	-	1.021	-	-	9.415

Table B-4. --(Continued).

Shot No.	Gauge No.	Rate, ft Sec	Peak Pressure, psi	Impuse, psi-msec	Energy, in.-lb/in. ²	Cut-Off Time, msec	Theta, msec	Negative Pressure, Psi	Time Interval Between Shocks, msec
									Vert. Horiz.
133	3257	26	24.4	59.6	50.2	3.29	0.173	0.098	151
	3412			54.7	51.6	3.34	0.174	0.098	126
	3414			57.0	50.6	3.31	0.173	0.111	12
Mean				58.8	50.6	3.31	0.173	0.102	116
3264a				28	3.1	0.01	0.267	-	5.94
152	3257	2c	24.4	47.6	41.1	2.27	0.167	-	58
	3412			47.7	41.2	2.36	0.164	-	97
	Mean			47.8	41.5	2.32	0.166	-	78
136	3257	26	24.4	56.8	42.4	3.02	0.124	0.111	91
	3412			54.0	38.5	2.48	0.130	0.096	83
	3264			56.3	46.2	3.18	0.142	0.117	83
134				57.9	35.3	2.45	0.113	0.081	99
	Mean			56.2	40.6	2.78	0.127	0.101	89

Table B-4. --(Continued).

		RANGE, ft.	PEAK PRESSURE, psi	IMPULSE, psi·msec	ENERGY, in.-lb/in. ²	CUT-OFF TIME, msec	THETA, msec	Negative PRESSURE, psi	TIME INTERVAL BETWEEN SHOCKS, msec
137	3257	30	28.6	467	34.0	2.01	0.121	0.109	65
	3412			462	34.7	2.95	0.126	0.102	76
	3264			489	37.0	2.30	0.123	0.116	-
	3414			487	33.1	2.92	0.113	0.103	42
Mean				481	34.7	2.10	0.121	0.108	62
151	3412	34	32.8	383	29.7	1.35	0.140	0.110	61
	3257			416	27.4	1.47	0.106	0.102	119
	3412			415	26.9	1.45	0.105	0.101	-
	3264			363	27.9	1.45	0.110	0.119	80
	3414			404	27.7	1.47	0.106	0.112	82
Mean				407	27.5	1.46	0.107	0.108	-
134	3257	38	36.0	386	24.6	1.24	0.101	0.104	56
	3412			384	24.2	1.21	0.079	0.103	-
	3264			376	23.4	1.16	0.096	0.105	77
	3414			375	23.4	1.19	0.093	0.111	63
Mean				381	23.0	1.20	0.097	0.106	73
									-

Table B-4. --(Continued).

Sight No.	Gauge No.	Range, ft	Peak Pressure, psi	Impulse, psi-msec	Energy, in. lb/in. 2	Cut-Off Time, msec	Theta, msec	Negative Pressure, psi	Time Interval Between Shocks, msec
141	3257	46	45.1	310	15.1	0.77	0.087	0.102	64
	3412			314	15.2	0.77	0.089	0.105	-
	3264			361	16.4	0.79	0.086	0.128	67
	3414			297	18.2	0.77	0.084	0.132	78
<hr/>									
Near									
151	3257	46	45.1	274	1F.2	0.65	0.104	0.110	71
									-
170	3257	56	55.3	256	14.3	0.46	0.084	0.097	95
	3412			259	14.5	0.46	0.092	0.062	-
	3414			223	13.0	0.48	0.084	-	57
<hr/>									
Mid									
				246	14.2	0.49	0.087	0.080	81
	3264a			124	6.3	0.09	0.165	-	-
									3.350

Table B-4. --(Continued).

Sht.	Gauge No.	Range, ft		Peak Pressure, psig	Impulse, psi msec	Energy, in. lb/in. 2	Cut-Off Time, msec	Theta, msec	Negative Pressure, psi	Time Interval Between Shocks, msec
		Start	Horiz.							
203	3257	z ₀	55.3	254	13.6	0.47	0.079	0.104	105	-
	3412			260	13.3	0.49	0.079	0.074	NRb	-
	3414			241	14.6	0.53	0.079	0.156	64	-
	3414			252	15.3	0.50	0.076	0.126	63	-
Mean				253	14.8	0.50	0.078	0.120	57	-
										3.322
	3414									-
	3264a									-
211	3257	z ₀	55.3	311	11.3	0.34	0.077	0.102	90	-
	3412			225	11.7	0.34	0.076	0.086	51	-
	3414			213	12.3	0.35	0.079	0.125	64	-
Mean				211	11.7	0.35	0.077	0.106	78	-
										3.311
	3414									-
	3264a									-
147	3257	z ₀	55.3	262	6.7	0.31	0.061	0.156	60	-
	3412			212	11.1	0.35	0.074	0.136	52	-
Mean				207	10.4	0.33	0.068	0.146	56	-

Table B-4.--(Continued).

Shot No.	Gauge No.	Range, ft Slant	Peak Pressure, psi	Impulse, psi-msec	Energy, in. · lb/in. ²	Cut-Off Time, msec	Theta, msec	Negative Pressure, psi	Time Interval Between Shocks, msec
207	3257	78	77.5	17.1	6.7	0.16	0.057	0.065	52
	3412		178	178	7.0	0.17	0.058	0.064	61
	3414		143	6.2	0.14	0.056	0.108	26	-
	3264		149	6.5	0.14	0.057	0.106	49	-
Mean			150	6.6	0.15	0.057	0.086	47	-
147	3257	78	77.5	155	6.6	0.16	0.052	0.138	36
	3412		150	6.4	0.15	0.054	0.152	30	-
	3254		156	6.6	0.17	0.052	0.172	34	-
	3414		161	7.0	0.18	0.054	0.135	42	-
Mean			156	6.6	0.16	0.053	0.149	36	-
154	3412	78	77.5	157	6.2	0.14	0.055	0.102	42
	3257		139	5.0	0.10	0.049	0.076	36	-
	3412		136	4.7	0.09	0.048	0.069	35	-
	3414		131	5.2	0.10	0.050	0.109	19	-
	3264		139	5.0	0.10	0.051	0.058	34	-
Mean			136	5.0	0.10	0.050	0.078	31	-
	3414		-	-	-	-	-	-	2.458

Table B-4. --(Continued).

Shot No.	Gauge No.	Rang, ft	Peak Pressure, psi	Impulse, psr·msec	Energy, in.·lb/in.²	Cut-Off Time, msec	Theta, msec	Negative Pressure, psi	Time Interval Between Shocks msec
153	3257	110	109.6	1.65 1.84	4.3 0.07	0.08 0.047	0.046 0.169	0.175 0.26	26 27
	3412								
Mean									
192	3257	130	129.6	1.13 1.06	3.1 3.2	0.05 0.05	0.036 0.040	0.061 0.062	33 34
	3412								
Mean									
	3414a								
193	3257	130	129.6	1.07 1.06	3.0 2.9	0.05 0.05	0.036 0.035	0.061 0.063	28 29
	3412								
Mean									
	3414a								
	3264a								

Table B-4. --(Continued).

Shot No.	Gauge No.	Range, ft	Peak Pressure, psi	Impulse, psi·msec	Energy, in.-lb/in.²	Cut-Off Time, msec	Theta, msec	Negative Pressure, psi	Time Interval Between Shocks, msec
		Slant	Horiz.						
190	3257	130	129.6	106	2.3	0.04	0.029	0.060	25
	3412			105	2.3	0.04	0.028	0.067	31
Mean				106	2.3	0.04	0.028	0.064	28
	3414 ^a			-	-	-	-	-	1.271
191	3257	130	129.6	107	1.8	0.03	0.023	0.053	25
	3412			112	1.8	0.03	0.023	0.044	23
Mean				110	1.6	0.03	0.023	0.048	24
	3414 ^a			-	-	-	-	-	1.271

^a Bottom reflector parameters.^b Not readable.

Table B-5. --Pressure-time parameters measured at 2-ft depths when 1-lb charges were detonated at 10-ft depths.

Shot No.	Gauge No.	Range, ft	Peak Pressure, psi	Impulse, psi msec	Energy, in. · lb/in.²	Cut-Off Time, msec	Theta, msec	Negative Pressure, psi	Time Interval Between Shocks, msec
175	3257	33	32.5	42.7	44.7	1.96	0.249	0.114	NR ^b
	3412		43.6	42.9	4.95	0.226	0.039	NR	-
	3414		43.2	45.5	2.11	0.221	0.121	NR	-
Mean									
	3254 ^a								
176	3257	54	31.4	27.2	21.8	2.64	0.161	0.070	103
	3412		44.0	24.0	26.9	0.50	0.153	0.097	81
	3414		36.5	26.5	23.4	0.71	0.159	0.112	77
Mean									
	3254 ^a								
177	3257	73	32.6	1.47	3.4	0.18	0.095	0.116	60
	3412		45.3	9.7	0.19	0.108	0.107	60	-
	3414		45.1	9.9	0.20	0.099	0.113	45	-
Mean									
	3254 ^a								

^a Bottom reflection parameters.

^b Not readable.

Table B-6.--Pressure-time parameters measured at 10-ft depths when 1-lb charges were detonated at 10-ft depths.

Shot No.	Gauge No.	Range, ft		Peak Pressure, psi	Impulse, psi-msec	Energy, in. · lb/in. 2	Cut-Off Time, msec	Theta, msec	Negative Pressure, psi	Time Interval Between Shocks, msec
		Sht.	Slant							
168	3257	48	48	26.0	45.0	1.03	6.748	0.124	64	-
	3412			25.0	44.5	0.91	6.849	0.132	69	-
	3414			27.0	47.1	0.98	0.831	0.129	57	-
Mean				26.9	45.5	0.97	6.609	0.128	63	-
	3264 ^a			14.5	40.0	0.18	0.136	0.089	-	2.545
163	3257	42	42	27.2	47.2	0.90	0.807	0.139	NR ^b	-
	3412			26.3	47.4	1.12	0.763	0.110	NR	-
	3414			26.1	47.4	0.57	0.808	0.127	NR	-
Mean				27.2	47.5	1.00	0.793	0.128	NR	-
	3264 ^c			14.6	18.9	0.45	0.221	-	-	2.593
167	3257	84	84	15.9	23.1	0.29	0.512	0.116	37	-
	3412			15.4	19.4	0.23	0.517	0.094	NR	-
	3414			15.1	25.8	0.34	0.518	0.134	34	-
Mean				15.3	22.8	0.29	0.516	0.115	36	-
	3264 ^d			15.4	3.1	0.95	0.098	-	-	1.594

Table B-6. --(Continued).

Shot No.	Gauge No.	Range, ft		Peak Pressure, psi	Impulse, psi-msec	Energy, in. · lb/in. 2	Cut-Off Time, msec	Theta, msec	Negative Pressure, psi	Time Interval Between Shocks, msec
		Start	Horiz.							
164	3257	84	84	157	22.7	6.31	0.484	0.124	44	-
	3412			168	23.5	0.33	0.491	0.114	59	-
	3264			155	22.8	0.31	0.478	0.122	56	-
	3414			145	21.5	0.27	0.463	0.118	47	-
Mean				157	22.7	0.30	0.479	0.120	52	-
171	3257	84	84	176	19.4	6.39	0.585	0.099	41	-
	3412			157	22.3	0.31	0.455	0.131	39	-
	3414			161	23.4	0.35	0.448	0.129	36	-
Mean				166	21.7	0.32	0.429	0.120	35	-
3264 ^a				42	6.8	0.004	0.060	-	-	1.664

^a Broken reflection parameters.^b Not readable.

Table B-7.--Pressure-time parameters measured at 1-ft depths when 1-lb TNT charges were detonated at 10-ft depths (dog eardrum tests).

	Gauge No.	Range, ft	Peak Pressure, psi	Impulse, psi-msec	Energy, lb/in. ²	Cut-Off Time, msec	Theta, msec	Negative Pressure, psi	Time Interval Between Shocks, msec
Sheet No.		Slat	Horiz.						
164	3414	20.0	17.9	655	69.5	4.83	0.220	62	-
	3264		696	67.0	4.77	0.208	0.089	75	-
Mean			676	65.2	4.80	0.214	0.097	68	-
				56	6.5	0.04	0.430	-	5.569
Mean	3257 ^a		-	-	-	-	-	-	5.705
	3414 ^a			56	6.5	0.04	0.481	-	5.637
195	3414	40.0	31.9	21.5	0.97	0.113	0.106	75	-
	3257 ^a		-	-	-	-	-	-	4.244
Mean	3414 ^a		-	-	-	-	-	-	4.222
				-	-	-	-	-	4.233
204	3412	49.0	39.0	335	22.1	0.95	0.105	100	-
	3414		321	23.5	1.61	0.110	0.123	56	-
Mean	3264		326	22.6	0.97	0.106	0.124	96	-
			327	22.7	0.98	0.108	0.117	84	-
Mean	3264 ^a		96	12.5	0.10	0.443	-	-	4.053
	3414 ^a		-	-	-	-	-	-	-

Table B-7. --(Continued).

Shot	Charge No.	Ranee, ft.	Peak Press., ps.	Impulse, lb.-sec.	Energy, in.·lb./in.	Cut-Off Time, msec	Theta, msec	Negative Pressure, psi	Time Interval Between Shocks, m.sec
208	3257	41.1	34.0	324	26.3	0.84	0.09	0.101	118
	3412	-	-	330	21.3	0.92	0.107	0.103	110
	3413	-	-	322	22.7	0.87	0.104	0.108	-
	3254	-	-	333	21.1	0.49	0.101	0.344	109
Mean	-	-	-	28	21.5	0.41	0.105	0.102	93
	3264 ^a	-	-	76	12.5	0.17	0.414	-	-
	3414 ^a	-	-	-	-	-	-	-	4.021
	-	-	-	-	-	-	-	-	-
210	3257	41.0	32.6	324	26.2	0.82	0.104	0.081	96
	3412	-	-	31	24.4	0.84	0.107	0.106	96
	3413	-	-	31.7	23.1	0.77	0.103	0.119	32
	3254	-	-	30.7	26.1	0.77	0.105	0.065	86
Mean	-	-	-	31.7	26.4	0.80	0.105	0.068	77
	3264 ^a	-	-	75	12.7	0.16	0.437	-	-
	3414 ^a	-	-	-	-	-	-	-	4.021
	-	-	-	-	-	-	-	-	-
267	3414	45.0	44.1	374	16.6	0.75	0.099	0.192	61
	3264	-	-	373	18.8	0.73	0.091	0.077	65
	-	-	-	-	-	-	-	-	-
	Mean	-	-	262	14.2	0.76	0.069	0.134	63
3257 ^a	-	-	-	-	-	-	-	-	3.577
	3412 ^a	-	-	107	13.2	0.13	0.345	-	-
	3413 ^a	-	-	-	-	-	-	-	3.775
	3254 ^a	-	-	112	15.8	0.15	0.391	-	-
Mean	-	-	-	111	14.3	0.15	0.365	-	3.672

Table B-7. --(Continued).

		Range, ft	Peak Pressure, psi	Impulse, psi-msec	Energy, in. ² lb/in. 2	Cut-Off Time, msec	Theta, m.sec	Negative Pressure, psi	Time Interval Between Shocks, msec
Shot No.	Gauge No.	Slant	Horiz.						
	3257	45.0	44.1	287	17.7	0.70	0.088	0.122	102
	3412			305	19.3	0.79	0.094	0.114	111
	3414			282	19.2	0.79	0.092	0.150	72
Mean	3264			297	19.6	0.82	0.095	0.142	92
	3264 ^a			293	19.0	0.78	0.092	0.132	94
	3414 ^a			107	13.3	3.14	0.389	-	-
					-	-	-	-	3.857
197	3414	60.0	59.3	200	12.4	0.38	0.078	0.211	43
	3264			230	12.4	0.40	0.077	0.082	49
	Mean			215	12.4	0.39	0.078	0.146	46
									-
Mean	3257 ^a			80	-	-	0.122	-	3.122
	3414 ^a			89	-	-	0.170	-	3.000
	84			-	-	0.146	-	-	3.061
									-

^a Bottom reflection parameters.

Table B-8. -- Pressure-time parameters measured at 1-ft depths when 3-lb charges were detonated at 10-ft depths.

Shot No.	Gauge No.	Range, ft Siant Horiz.	Peak Pressure, psi	Impulse, psi msec	Energy, in.-lb/in. 2	Cut-Off Time, msec	Theta, msec	Negative Pressure, ps:
143	3257	36	34.9	52.7	2.84	0.103	0.144	.20
	3412			53.4	2.98	0.110	0.145	1.01
	3264			54.2	3.32	0.110	0.166	1.04
	3414			53.6	39.7	3.05	0.102	0.57
Mean				53.6	40.3	3.05	0.106	0.88
144	3257	61	60.3	30.3	16.4	0.77	0.059	0.160
	3412			29.7	15.4	0.72	0.065	0.176
	3264			29.7	16.4	0.78	0.068	0.202
	3414			30.0	15.3	0.73	0.063	0.176
Mean				29.9	15.6	0.75	0.066	0.178
146	3257	72	71.4	24.6	12.4	0.49	0.063	0.208
	3412			23.8	11.6	0.44	0.061	0.202
	3264			25.5	11.0	0.45	0.054	0.158
	3414			25.3	12.0	0.49	0.058	0.188
Mean				24.8	11.8	0.47	0.059	0.189
150	3257	97	96.6	18.9	7.7	0.21	0.047	-
	3412			18.6	6.7	0.20	0.044	3.1
	3264			19.7	8.4	0.27	0.051	2.3
	3414			19.1	7.1	0.23	0.047	2.6
Mean								2.7

Table B-9.--Pressure-time parameters measured at 1-ft depths when 8-lb charges were detonated at 10-ft depths.

Shot No.	Gauge No.	Range, ft	Peak Pressure, psi	Impulse, psi·msec	Energy, in.·lb/in. ²	Cut-Off Time, msec	Theta, msec	Negative Pressure, psi
		Slant	Horiz.					
140	3251	52	51.2	557	34.4	3.02	0.076	0.199
	3412			558	31.9	2.77	0.072	0.179
	3264			553	33.2	2.93	0.074	0.218
	3414			556	33.2	2.94	0.073	0.206
Mean				556	33.2	2.92	0.074	0.200
142	3257	60	59.3	477	26.3	2.02	0.067	0.212
	3412			480	27.7	2.12	0.071	0.210
	3264			474	26.0	2.00	0.066	0.223
	3414			478	25.6	1.99	0.064	0.216
Mean				477	26.4	2.03	0.067	0.215
							64	63

Table B-10. --Pressure-time parameters measured at 1-ft depths when 1-lb TNT charges were detonated at 10-ft depths (tests to measure bottom reflections, no targets).

Shot No.	Gauge No.	Range, ft	Peak Pressure, psi	Impulse, psi·msec	Energy, in.·lb/in.²	Cut-Off Time, msec	Theta, msec	Negative Pressure, psi	Time Interval Between Shocks, msec
196	3414	40	39.0	-	23.0	0.96	0.112	0.125	-
	3257a	-	84	10.5	-	-	-	-	4.244
	3412a	-	-	-	0.07	0.346	-	-	-
	3414a	-	-	11.0	11.3	0.09	2.403	-	4.222
	3264a	-	97	10.9	0.08	6.274	-	-	-
Mean		59.3	21.6	11.5	0.65	0.675	0.096	52	4.233
199	3414	60	23.	10.5	0.31	0.671	0.348	61	-
	3264	-	226	11.6	0.33	0.073	0.072	56	-
Mean		59.3	23.	11.6	0.33	0.073	0.072	56	-
	3257a	-	93	6.7	0.05	-	0.145	-	3.200
	3412a	-	-	-	-	-	-	-	-
	3414a	-	126	6.3	0.08	0.136	-	-	3.0±3
	3264a	-	109	6.5	0.08	0.140	-	-	-
Mean		59.3	23.	6.5	0.08	0.140	-	-	3.122

Table B-10. --(Continued).

Shot No.	Gauge No.	Range, ft		Peak Pressure, psi	Impulse, psi·msec	Energy, in.·lb/in. ²	Cut-Off Time, msec	Theta, msec	Negative Pressure, psi	Time Interval Between Shocks, msec
		Slant	Horiz.							
201	3414 3264	80	79.5	183	8.1	0.22	0.058	0.112	39	-
				178	7.8	0.22	0.056	0.089	38	-
				180	8.0	0.22	0.057	0.100	38	-
Mean										
	3257a 3412a 3264a			-	-	-	-	-	-	2.922
				78	-	-	-	-	-	2.750
				68	1.9	0.01	0.133	-	-	-
Mean				73	1.9	0.01	0.133	-	-	2.836

a Bottom reflection parameters.